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EVALUATION OF EVAPOTRANSPIRATION-BASED SEPTIC SYSTEMS ("EVAPOBEDS") FOR TREATMENT OF DOMESTIC SEWAGE IN ESSEX COUNTY, ONTARIO

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EVALUATION OF EVAPOTRANSPIRATION-BASED SEPTIC SYSTEMS ("EVAPOBEDS") FOR TREATMENT OF DOMESTIC SEWAGE IN ESSEX COUNTY, ONTARIO

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EXECUTIVE SUMMARY

The performance of evapotranspiration-based, partially-raised septic systems for the treatment of domestic sewage in Southwestern Ontario was assessed through inspection, interviews with their owners, tracer additions, environmental monitoring and climate-based models. Inspection of 60 systems took place in February and March of 1996, monitoring of 30 sites was conducted in April and May of 1996 and the modelling study used climatic records for the period from January of 1961 to December of 1995.

Results of these studies indicate that, whether based on climatic models of potential evapotranspiration or on direct monitoring of environmental impact, evapotranspiration-based septic systems are not an effective, year-round means of treating domestic sewage in Southwestern Ontario. Hydraulic connection of evapotranspiration-based systems with adjacent surface waters was demonstrated in 47% of 30 systems studied and there was evidence of nutrient enrichment of adjacent surface waters by partially-treated sewage effluent at 66% of the study sites. There was no evidence, however, that properly built and maintained evapotranspiration-based septic systems lost bacteria to receiving waters and no complaints from users or the community-at-large relating to their operation.

This study represents a compromise between the need for a full assessment and understanding of a poorly known technology, and the practical implementation of a study design. Interpretation of the study would have been improved by the inclusion of more piezometers to monitor the volume and quality of effluent within these systems and to increase the probability of intercepting effluent, more intensive study of nutrient chemistry of piezometer samples and surface water adjacent to study sites and an extended monitoring period, to cover the November to March period when frozen ground prevents evapotranspiration.

Although routine utilization of high densities of evapotranspiration-based systems could impair the quality of adjacent surface waters, the impacts of the approximately 1800 existing systems appears to be negligible in comparison with the predominance of agricultural runoff, the overall poor quality of surface waters adjacent to the septic systems and their use in rural areas with a low density of residential development. The environmental impacts of evapotranspiration-based septic systems are of greatest potential concern where cumulative effects due to repetitive impacts at one site, repeated impacts over a large area or failures associated with extreme climatic events are considered. Not enough is known about the performance of conforming or alternative private septic systems, however, to make valid comparisons of the preferred means of on-site treatment of domestic sewage in heavy clay soils.

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1.0 BACKGROUND

Since 1989, the Directors responsible for implementing MOEE's Part VIII program for on-site sewage systems in Essex and Kent Counties have been approving a form of partially-raised septic system which has become known as an evapotranspiration-based septic system ("evapobed" or "ET bed"). These systems are an alternative to conventional, in-ground septic systems or fully raised-bed systems. Because several elements of their design differ from the standards prescribed by Regulation 358 of Ontario's Environmental Protection Act, they can only be approved for sewage treatment and disposal in Ontario as non-conforming systems.

Evapotranspiration-based septic systems were developed as a result of continuing problems in heavy clay soils which allow very little infiltration of effluent. Prior to 1957, sewage was often discharged directly to tile drains (and hence the nearest receiving water) with minimum treatment. Ontario's Public Health Act of 1957, and the Ontario Water Resources Act of 1974, forbade the discharge of untreated sewage to surface water. At that time, in-ground tile fields became the preferred means of domestic sewage treatment. These operated on the principle of discharge of treated sewage effluent to groundwater. Approximately 300 in-ground systems were installed each year between 1974 and 1989. Poor infiltration of effluent to the groundwater resulted in a high rate of breakout and ponding of sewage effluent on the surface, however, and many in-ground systems were connected to surface water by way of an illegal overflow to compensate for such failure.

One alternative to in-ground septic systems became the fully raised tile field with the addition of an aerobic digester for primary treatment Approximately 60 of these were were installed in Essex County prior to 1989. All of these have failed for various reasons; ranging from mechanical unreliability, insufficient contact area in the filterbed and insufficent mantle area to maximize evapotranspiration. Installations of fully raised tile beds in Kent County which used a unidirectional mantle also demonstrated an unsatisfactory failure rate. Performance of these systems was somewhat improved after 1992 with the addition of an omni-directional mantle, which increased the land requirement for a sewage envelope to 2500m^2. Systems built to these standards in the similar soils of Lambton County remain in service. These standards require a minimum 2500 m^2 sewage envelope, however, to accommodate the lower infiltration rates of the clay soils. This has increased the minimum lot-size requirement for rural severances to 3700 m^2 in Essex and Kent Counties. The history of unsatisfactory performance, the requirements for increased lot sizes, the high cost of a fully-raised system ($20-25,000) and resident's perceptions that fully-raised systems are unsightly have combined to encourage the development of an alternative septic system for use in Essex and Kent Counties. A comparison of characteristics of system types is given in Table 1.

Evapotranspiration[1] (ET)-based septic systems are designed to discharge all effluent to the atmosphere rather than the underlying soil as in a traditional sewage system. Several thousand of these systems exist throughout the United States and Canada (Bennett and Linstedt 1978; Bernhart 1973). The traditional ET system design consists of a sand bed over an impermeable liner, either natural or artificial. However, in some areas on open basin is used (USEPA 1980). The sand bed may be planted with various types of vegetation or left bare. In all cases it is recommended that only pretreated effluent be discharged to the disposal area to reduce the collection of solids and salts on the evaporative surface (Otis 1996 - pers. comm. to Alex Campbell, Approvals branch, MOEE).

Table 1 Comparative features and operating characteristics of on-site sewage systems used in Essex and Kent Counties.

Period	**Type**	**Disposal**	**Size**	**Cost**	**Comments**
pre 1974	Drain to ditch	Surface water	<10m^2 (Septic tank)	--	Not approved
1974-1989	In-ground tile field	Ground water**	300 m^2	$5,000	Observed breakout Illegal connection to surface water Discontinued
1989	Fully raised tile field	Ground water	2500 m^2	$20,000	Approved Observed breakout Unpopular Discontinued
1989-1996	Evapotranspiration based system	Atmosphere** (water only)	1500 m^2	$10,000	No apparent problems Non-conforming

** presumed only

The effectiveness of the ET-based septic system is very dependent on local climate conditions. While ET systems have apparently been made to work in parts of Canada, the Northern United States, and mountainous areas, there is little detailed information available in the literature. Their year round use is normally considered feasible only where evaporation exceeds precipitation during every month the year (Perkins 1990). Attempts to modify systems to store effluent during periods of insufficient evapotranspiration have met with limited success (Perkins 1990). The greatest success with ET systems has been in the warm arid and semi-arid climatic region of North America (Perkins 1990). In other climatic zones they are typically used as a means of effluent disposal only for homes which are occupied only in the summer, when evaporation rates are at a maximum and dwelling use is minimal (USEPA 1980).

---

[1] Evapotranspiration is the conversion of liquid water to water vapour through a combination of evaporation and plant transpiration. Transpiration is the uptake of water by plant roots and the discharge of water vapour from plant leaves.

Evapotranspiration-based septic systems were adapted by staff of the Essex County Health Unit and approximately 1800 have been installed in Essex and Kent Counties since 1989. These systems are a hybrid design. They are excavated to a depth of 10" on the clay soils and partially raised to about 15" above grade (Fig. 1). They therefore require much less imported fill than do fully-raised systems and are less costly. They are much more visually appealing to property owners, as they are raised only slightly above grade. Although they appear to be popular with landowners and their use has generated no complaints they do not meet MOEE's prescriptive standards for approved septic systems.

There are no documented design details for this type of system outside of Ontario. The design of the systems installed in Essex and Kent Counties appears to be based on the work of Dr. Alfred Bernhart (1973, 1974, 1985). In the early 70's, staff of the Applied Science Branch and the Pollution Control Branch (now Approvals Branch) of MOEE had numerous discussions with Dr. Bernhart about his proposed system and carried out a critical review of his research. They concluded that Ontario did not have the climatic conditions necessary to use evapotranspiration as a year round means of effluent disposal, and that there was no conclusive evidence that the system proposed would operate successfully over the entire year.

In October of 1993, staff of MOEE Southwestern Region and Windsor District conducted a survey to determine if any adverse impacts arose from the use of these systems and to review the question of compliance with Regulation 358. A total of 35 sites were inspected and 3 sites fitted with perimeter piezometers and monitored over the winter months of 93\94. The results indicated no evidence of ponding, breakout or offsite environmental impact. Although the results were favourable the extent of the survey was found to be too small to statistically support any scientific recommendation to the Minister of Environment and Energy. A regulatory review at that time confirmed that the systems, as designed, did not conform to the Part VIII regulations and could only be approved by Part VIII Directors under the rules for discretion under Section 77 of the Environmental Protection Act.

So long as evapotranspiration-based systems remain as a non-conforming alternative, the fully-raised filter bed system, with its attendant requirements and expenses, is favoured by MOEE regulations. Local residents feel, however, that the fully raised beds do not function well and that it is unfair for the MOEE to force rural residents to install the expensive system when all indications are that the evapotranspiration-based systems work well. There have been numerous appeals to the Environmental Appeals Board, briefs to the Minister objecting to unfair practices, and a halt to development in the rural areas of Essex and Kent County.

In December of 1995, Science and Technology Branch of MOEE was asked to assist Regional Operations Division in completing an objective assessment of evapotranspiration-based systems and any associated impacts. The study design was finished in February of 1996 and site selection and inspection began shortly thereafter. Monitoring began in April after a 5 week, province-wide labour dispute and the final report completed in September of 1996.

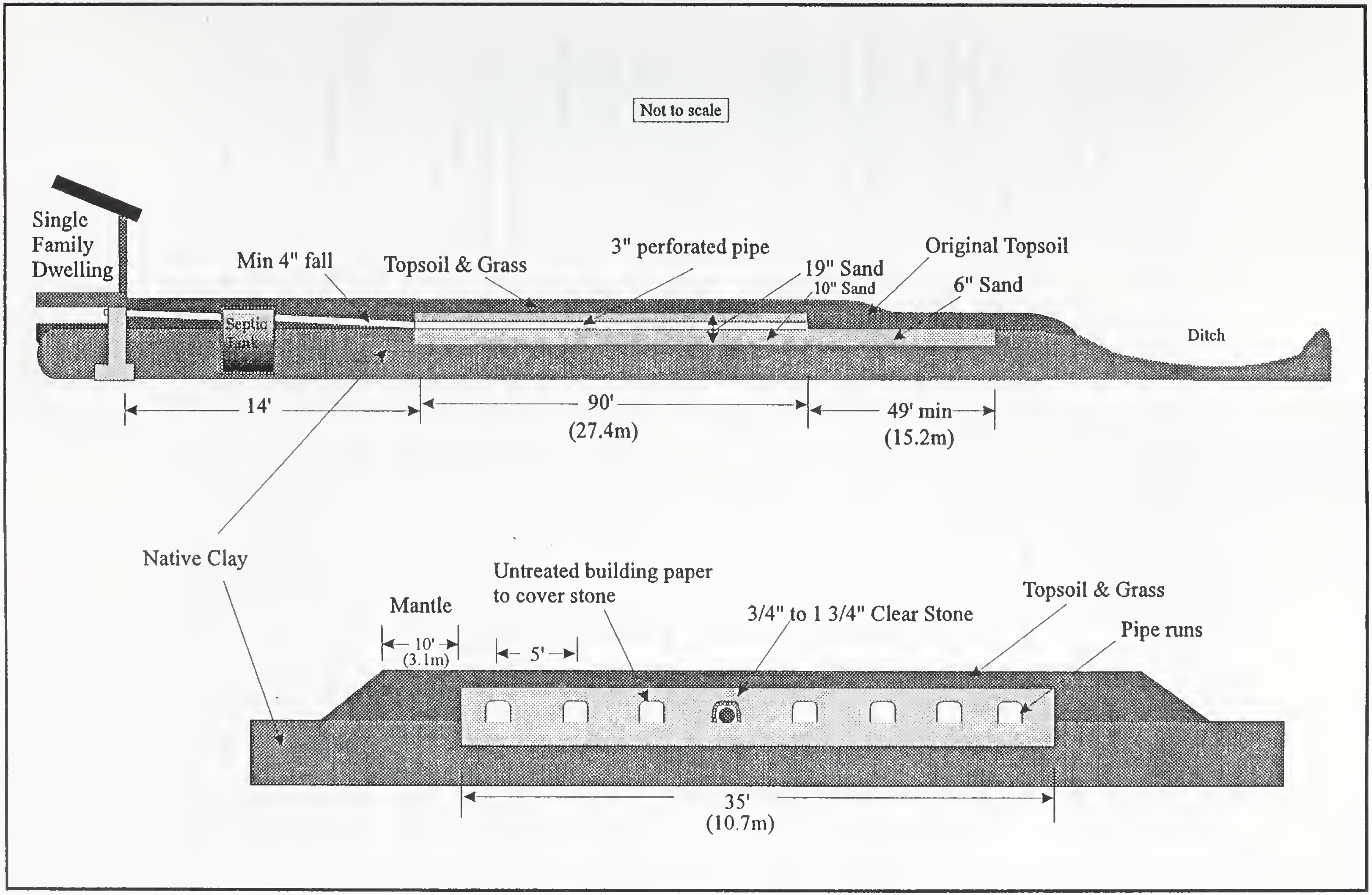


Fig. 1 Construction and dimensions of a typical partially-raised installation. Dimensions are those used in the modelling exercise.

2.0 PURPOSE

To review the operation and environmental acceptability of evapotranspiration-based septic systems ("evapobeds") for the treatment and disposal of domestic sewage in clay soils or other low infiltration environments in Ontario.

2.1 Study Objectives

1. Determine the theoretical basis for disposal of domestic sewage effluent by evapotranspiration using meteorologic records for Southwestern Ontario.

2. Determine the hydraulic performance of evapotranspiration-based systems by measuring dispersal of a tracer chemical from the septic system to surface water.

3. Determine the significance of any hydraulic failure by monitoring tracer bacteria and water quality indicators of domestic sewage pollution in surface waters adjacent to evapotranspiration-based systems.

4. Evaluate the performance of evapotranspiration-based systems by a visual insoection of installations and a survey of owners and users.

5. Evaluate any environmental impact of evapotranspiration-based septic systems in Southwestern Ontario.

2.2 Study Rationale and Performance Indicators

The study was designed to determine the performance of evapotranspiration-based systems in a chronological design. The working assumption was that a system must fail hydraulically - that is, it must fail to dispose of the total hydraulic load of effluent plus precipitation, before any environmental impacts could be determined. Any hydraulic failure must then manifest itself as detectable seepage of surface or near-surface water between the perimeter of the system and the nearest water course. Hydraulic performance was monitored both directly, by use of environmental tracers, and indirectly by the observations of system users.

An early evaluation was requested and, as a consequence, year round monitoring was not feasible. The study therefore focussed on late winter and early spring as the most likely periods when systems would fail. Evapotranspiration is minimal over the winter and so the septic systems would contain the maximum annual effluent volume. Snow melt and spring rains would add further loading to that from domestic sewage. If no failures were detected during the time of greatest hydraulic stress to the system, there would be little reason to suspect failure during the rest of the year. The survey of users was conducted during February and March but a province-wide labour dispute delayed the monitoring study to the period from early April to mid-May.

Any environmental impact of an hydraulic failure would be observed as the presence of sewage bacteria in adjacent surface water, or impairment of its water quality by indicators of domestic sewage such as elevated levels of ammonia, nitrate or phosphorus. Tracer studies were done to establish a hydrologic link between evapotranspiration-based systems and surface water. A limited monitoring program was conducted to establish any adverse environmental effect on surface waters. Sample sizes were chosen to be sufficiently large to avoid a false conclusion of no impact during the course of the study and covered a wide range operating conditions among users.

Finally, any observations must be substantiated by an understanding of the mechanisms of evapotranspiration and the theoretical basis for it's use. Construction of a hydrologic mass balance of a typical evapotranspiration-based system was used to determine the validity of evapotranspiration-based systems under the climatic conditions of southwestern Ontario. The model used potential evapotranspiration calculated using meteorologic data for the study area. If the model indicated that the method was feasible then the model would be extended to a broader range of representative climatic conditions to see where it could be applied in Ontario. The model was constructed for a 34-year period, from 1961 to the end of 1995 (the most recent data available). This time span was maximized to increase the probability of modelling a full range of climatic conditions.

2.3 Limitations

This study represents a partial compromise between the need for a full assessment and understanding of a poorly known technology, and the practical implementation of a study design. Interpretation of the study must be qualified by the knowledge that several key elements were dropped from the design over logistical concerns. In particular, interpretation would have been improved by :

- more detailed instrumentation with piezometers; to monitor volume and quality of effluent within these systems and to increase the probability of intercepting effluent from that possible with only two piezometers installed.

- more intensive study of nutrient chemistry of piezometer samples and surface water adjacent to study sites.

- including conventional fully raised septic systems in the study, for comparison of performance and environmental impact with that of evapotranspiration-based systems.

- an extended monitoring period, to cover the December to March period when frozen ground prevents evapotranspiration.

3.0 MATERIALS AND METHODS

3.1 Components of the Study

1. A hydrologic balance was constructed for a typical evapotranspiration-based system. Local meteorologic data and typical hydraulic loading rates were modelled to determine:

    a) Whether or not evapotranspiration would produce a net annual hydrologic deficit.
    b) The seasonality of hydrologic deficits and surpluses due to evapobed operation.
    c) The internal storage requirements for period of net hydrologic surplus.
    d) The climatic limits to the use of evapotranspiration-based systems in Ontario (if they worked in the study area)

2. Interviews with system owners and their records of water use were used to establish the prevalence of observable failure and hydraulic loading to evapotranspiration-based systems.

3. Lithium bromide was added to 31 systems as a tracer to determine whether or not effluent moved from evapotranspiration-based systems into surface water, or whether evapotranspiration, seepage losses and storage were sufficient to prevent any such movement. These studies took place in early spring when hydraulic loading was greatest.

4. A specialized form of the bacterium, *E. coli.*, useful as a tracer, was added to 9 systems in which LiBr studies had demonstrated an hydraulic connection to the surface water to determine any loss of sewage bacteria to the environment.

5. Surface water quality was sampled in the vicinity of evapotranspiration-based systems to determine whether or not partially treated sewage was discharged as a result of any failure. For the purposes of the study, surface water was defined as the near-surface groundwater collected by a piezometer at the downgradient edge of the mantle - that point where effluent would be most likely to be discharged into surface water.

6. Any ponding of water in the vicinity of evapotranspiration-based systems was noted and monitored for sewage indicators.

3.2 Site Selection and Usage/Problem Survey

Study sites were selected to represent typical systems, installed and operated according to the design criteria of Part VIII Directors in Essex and Kent Counties. The initial step involved review of all Certificates of Approval since 1989 for all evapotranspiration-based systems. In 1993, however, the design criteria were changed to incorporate a unidirectional mantle and so the emphasis was placed on the post-1993 systems. The primary parameters for study-site selection were that systems must have been :

- built on Brookson clay
- serviced by a metered municipal water supply
- serving a newly constructed single family dwelling
- on a site which was abutted by open storm sewer drains only
- hydraulically isolated from other septic systems to eliminate interference
- issued a Use permit following an uneventful final inspection
- installed in the summer instead of fall or spring

A site inspection and owner\occupant interview form (Appendix I) was used to compile information relevant to the survey. Specific information was gathered during the interview process on system details, system management and site inspection results. As the interviews and inspections progressed 30 typical sites were selected for the installation of piezometers in the area of the downgradient plume from the ET bed system. Study sites are shown in Fig. 2 and survey results summarized in Table 2.

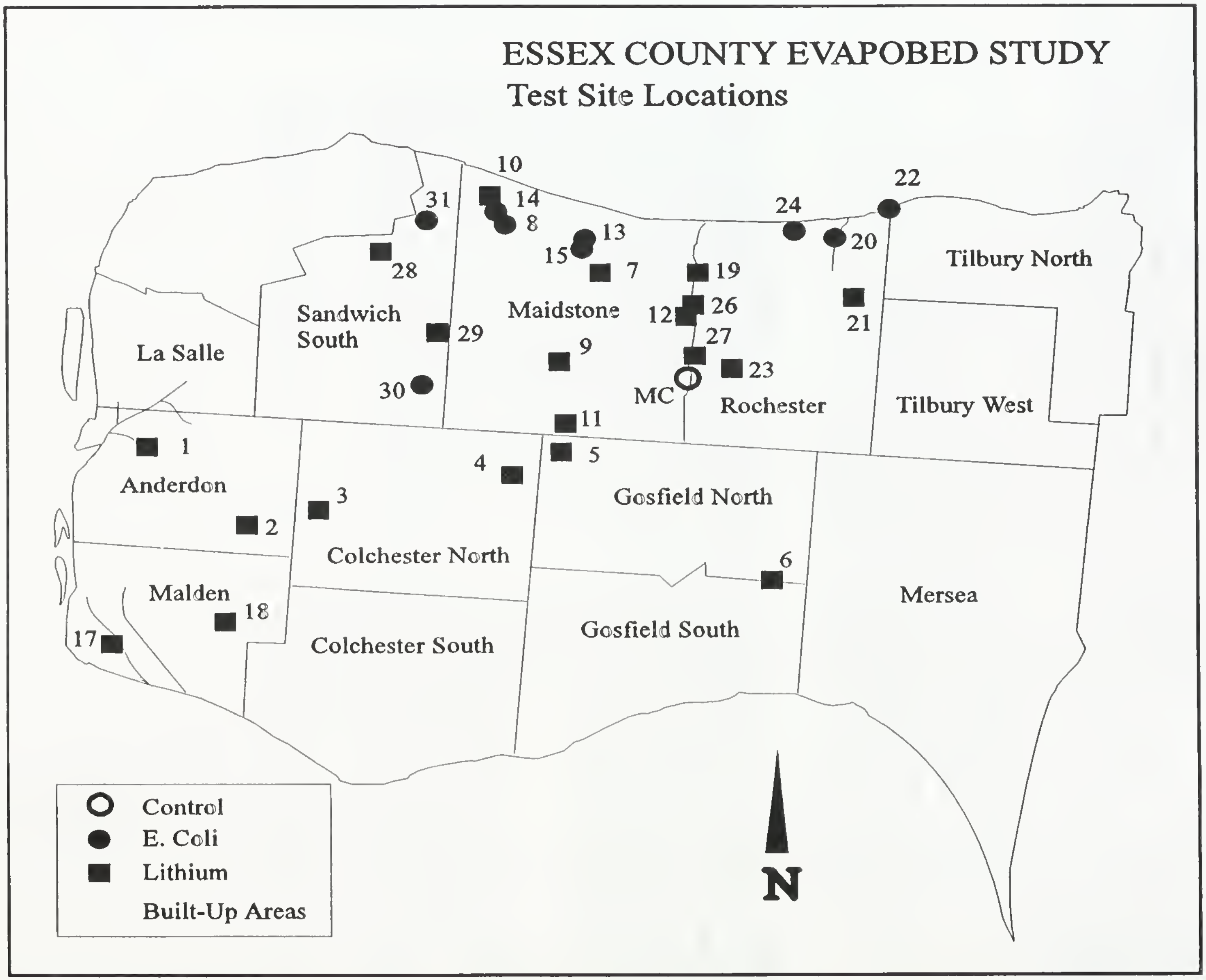


Fig. 2. Location of sites used for lithium and bacteria tracer studies.

Table 2 Evapotranspiration-based septic system study : Summary of sites selected for tracer studies. “MC” denotes damaged system used as a positive control (see text).

Site	Township	Date				No. of Persons			Water Use	Lith	Date	Toilet	Date	Toilet
		Cert. of Approval	Use Permit	Moved In	Survey Interview	Adult	Adolescent	Child	1995 Ave (L/day)	Toilet /Bed*	E. Coli Seeded	or Bed	Lithium Re-seeded	or Bed
1	Anderdon	Sep-94	Dec-94	Feb-95	28-Feb	3	1	0	1127	T	-	-	-	-
2	Anderdon	Mar-94	May-94	Jul-94	18-Mar	2	0	2	931	T	-	-	-	-
3	Colchester N	May-94	Aug-94	Aug-94	18-Mar	2	0	2	638	B	-	-	-	-
4	Colchester N	Feb-94	Aug-94	Aug-94	14-Mar	2	0	1	460	T	-	-	-	-
5	Gosfield N	Apr-94	Nov-94	Nov-94	27-Mar	5	0	1	1213	T	-	-	-	-
6	Gosfield N	Aug-94	Oct-94	Mar-95	21-Feb	2	0	3	ND	T	-	-	-	-
7	Maidstone	Sep-90	Oct-90	Sep-93	9-Feb	3	0	2	709	T	-	-	-	-
8	Maidstone	Aug-90	Aug-91	Aug-91	8-Feb	2	0	2	704	T	23-Apr	T	15-May	T
9	Maidstone	Mar-93	Dec-93	Feb-94	8-Feb	2	0	2	1175	B	-	-	-	-
10	Maidstone	Oct-94	Dec-94	Mar-95	23-Feb	2	0	5	468	B	-	-	-	-
11	Maidstone	Feb-93	May-93	Jul-93	16-Feb	2	0	2	852	T	-	-	-	-
12	Maidstone	Sep-92	Dec-92	Feb-93	19-Feb	5	0	2	920	B	-	-	-	-
13	Maidstone	Jun-94	Sep-94	Oct-94	18-Mar	2	0	3	994	T	7-May	T	13-May	T
14	Maidstone	Apr-94	Oct-94	Feb-95	15-Mar	4	0	0	1194	T	30-Apr	T	13-May	T
15	Maidstone	Jun-94	Aug-94	Oct-94	27-Mar	2	0	2	1093	T	7-May	T	13-May	T
16	Malden	May-94	Sep-94	Oct-94	10-Apr	2	0	0	ND	T	-	-	-	-
17	Malden	Sep-94	Nov-94	Feb-95	14-Mar	2	0	0	ND	T	-	-	-	-
18	Malden	Jul-94	Nov-94	Feb-95	10-Apr	2	0	2	454	T	-	-	-	-
19	Rochester	Jul-89	Dec-89	Jan-90	20-Feb	2	0	1	ND	T	-	-	-	-
20	Rochester	Jun-94	Sep-94	Jan-95	18-Mar	2	0	1	ND	T	30-Apr	T	13-May	T
21	Rochester	Jan-94	Aug-94	Sep-94	15-Feb	3	1	0	ND	B	-	-	-	-
22	Rochester	Apr-94	Sep-94	Mar-95	19-Mar	2	0	0	ND	B	30-Apr	T	13-May	T
23	Rochester	May-90	Jul-90	Aug-90	12-Feb	3	0	1	902	T	-	-	-	-
24	Rochester	Sep-94	Jun-95	Jul-95	14-Mar	2	0	2	ND	T	23-Apr	T	13-May	T
26	Rochester	Dec-94	Jun-95	Jun-95	19-Mar	3	0	0	ND	T	-	-	-	-
27	Rochester	Jun-90	Oct-90	Nov-90	12-Feb	2	0	2	1339	T	-	-	-	-
28	Sandwich S	Nov-92	Aug-93	Aug-93	9-Jun	4	0	0	1209	B	-	-	-	-
29	Sandwich S	Mar-94	Jun-94	Jun-94	18-Mar	2	0	2	325	T	-	-	-	-
30	Sandwich S	Jun-94	Sep-94	Jun-94	21-Feb	2	0	1	636	B	23-Apr	T	13-May	T
31	Sandwich S	Aug-91	Dec-91	Jan-92	9-Feb	2	2	0	ND	B	7-May	T	13-May	T
MC	Rochester	Apr-93	Oct-93	Nov-93	8-Feb	4	0	0	996	T	30-Apr	T	-	-

ND = No Data on water usage

* All sites seeded with Lithium April 2 - 4

3.3 Sample Size

Sample size for the monitoring program was calculated as a function of practicality and of detection limit. Detection of failed systems in the survey meant that results could be extrapolated from our sample size to estimate the total number of failed systems. The sample size had to be large enough, however, to prevent a false conclusion of no failure if no failed systems were found. In the absence of a conclusive statistical method the detection problem was restated as a problem of binomial proportions. The problem statement was therefore:

What is the proportion of failed systems in our population?

Cochran (1977) provided the following analysis:

Let p = proportion of failed systems in a population
q = proportion of satisfactory systems
n = number of samples required to detect p
d = given limit of acceptable error around the estimate of p
t = probability classification for 95% confidence in estimate (=2 for 0.05)

If p = 10%, d = 5%, our precision allows us to detect failure proportions of between 5 and 15% (10%),19 times out of 20, with a sample size of 144

$$n = \frac{t^2(pxq)}{d^2} = \frac{4(0.1x0.9)}{0.0025} = 144$$

If p = 10%, d = 10%, our precision allows us to detect failure proportions of between 0-20% (10%) 19 times out of 20 with a sample size of 36.

$$n = \frac{4(pxq)}{d^2} = \frac{4(0.1x0.9)}{0.01} = 36$$

It was only feasible to sample 30 sites and so the given error rate was considered acceptable.

3.4 Tracer Studies

Each of the 30 sites were instrumented with 2 piezometers and swale sumps within a few days after the first spring thaw and well in advance of the spring runoff season. Piezometers were at the outer end of the mantle within 3-5m of the swale or ditch (Fig. 3). Piezometers were placed to maximize their possibility of intercepting effluent, in locations which appeared to be at the lowest gradient from the system. Sumps were installed by digging holes in the downgradient end of the swale in front of each site and placing 500 mL plastic bottles so that surface runoff would intercept the mouth of each bottle, depositing sediment and any related bacteria.

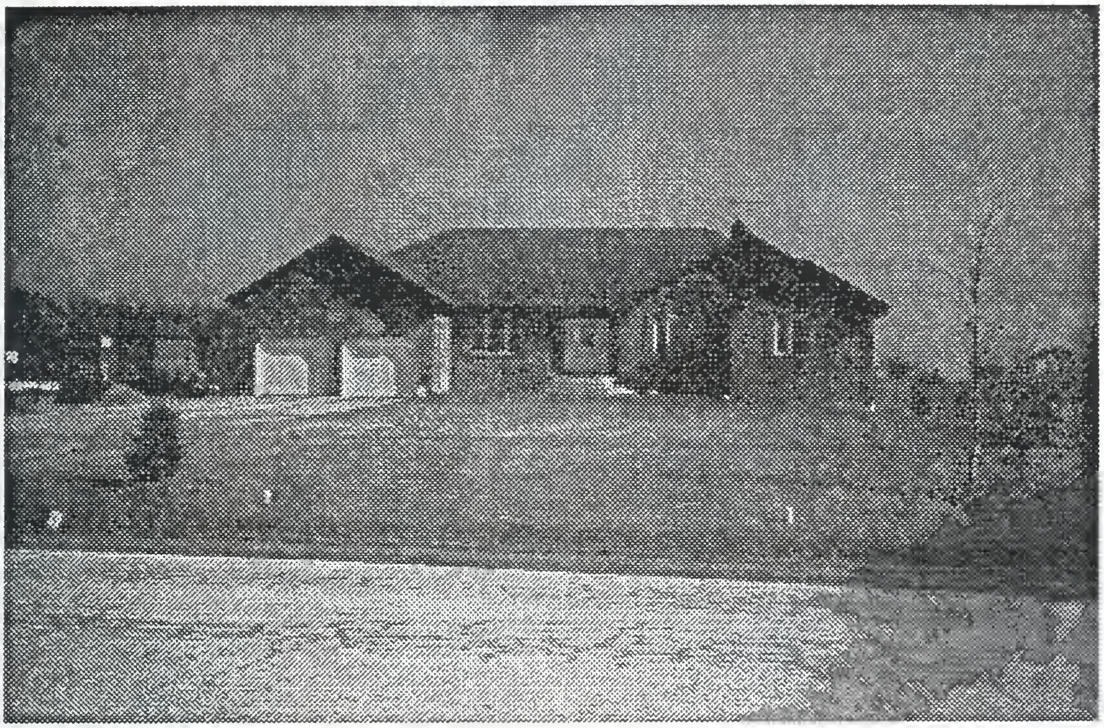


Fig.3 Typical installation of piezometers at a residence for tracer studies. Peizometers are visible as white pipes in the foreground.

Piezometers were made of 70 cm sections of 5 cm diameter PVC pipe, with fine mesh screening installed in the lower 60 cm. These were placed in 60 cm deep holes bored into the ground and sealed from surface infiltration with bentonite clay (Fig. 4). They would therefore intercept any seepage moving in the topsoil of the near subsurface, but were isolated from surface runoff.

3.4.1 Lithium Tracers

Lithium bromide was dosed into each residence, either into the toilet or by boring a hole into the septic system and dosing directly (Table 2). Doses were calculated to produce a Li concentration of 1-2 mg/L at the edge of the mantle, assuming full and rapid mixing within the evapobed. All systems were dosed between April 2 and 4th, 1996 and sampled for the first time on April 10. Sampling continued twice weekly until all systems dried up on May 18. Lithium was also sampled from tile drains which were adjacent to, but hydraulically separated from, the study sites to serve as reference values for comparison (Figs. 5, 6). Lithium was analyzed by Flame Atomic Absorption Spectrophometry with a detection limit of 1 µg/L and a between-run precision of 1-2 µg/L (average error = 11% for 64 duplicate analyses).

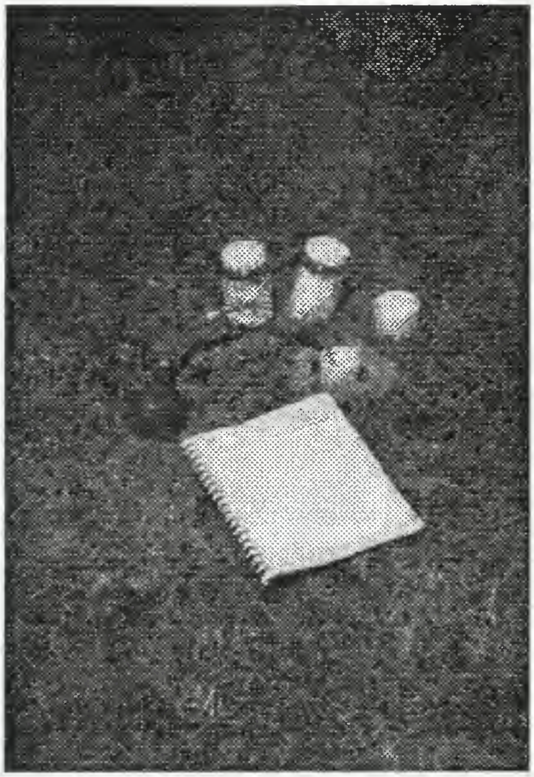


Fig. 4 Detail of piezometer installation, showing bentonite seal and sampling tube.

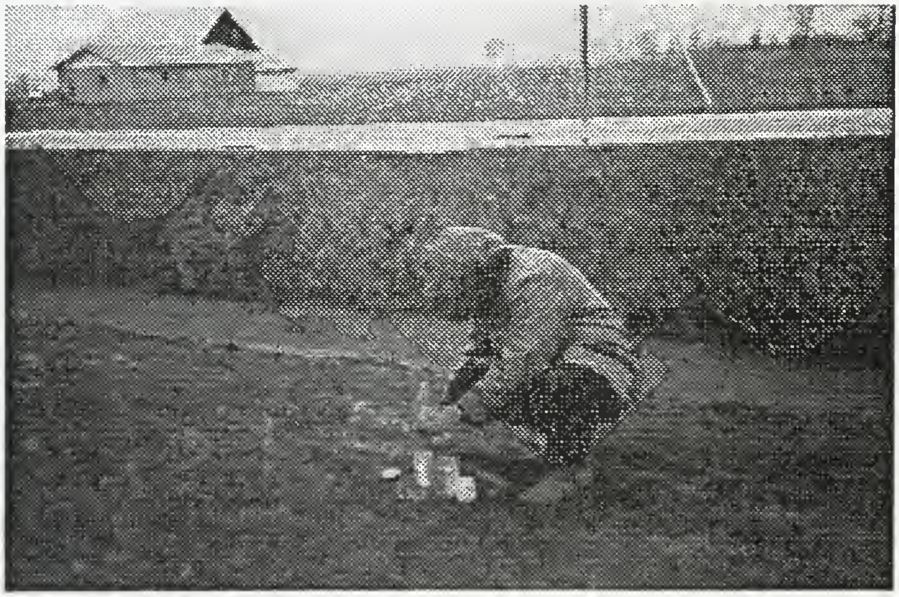


Fig. 5 Sampling water from the piezometer. Nearest surface water is shown in the ditch, 2 m from the piezometer.

3.4.2. Bacterial Tracers

Residences were selected for seeding with tracer bacteria on the basis of detection of Li in the piezometer samples. Three systems were seeded on each of April 23, April 30 and May 7 for a total of nine test sites. One system which had been damaged and was observed to be failing was seeded with Li and bacteria on April 30. The bacterium used was a strain of *Escherichia coli*, selected for tolerance to the antibiotic naladixic acid. It was added to each system via the toilet to achieve a concentration of 30500 bacteria/mL in the septic system (Table 3). Piezometers were sampled daily (except for weekends) until May 18 when they were dry.

Neither Li nor bacteria were directly measured in the septic tank and so dosing efficiency could not be determined.

Table 3 Calculation of dosage and concentration of tracer coliform for septic study.

Calculation of attenuation.

Data: dosage: 4 litre of 4.8 x 10 E8 bacteria/ml

bed/mantle storage volume:

surface area:	600 m^2
max. saturated depth:	0.35 m
% porosity:	30
storage volume:	63 m^3 or 63000 litre

Assume:
1. bed/mantle fully saturated, i.e. to max depth of 35 cm;
2. equal distribution of bacteria concentrate throughout bed/mantle area.

Final concentration is:

total dosage/total storage volume = 4000 ml x 4.8 x 10 E8 bacteria/ml / 63,000 litre

= 1.92 x 10E12 / 63x10E6 mL

= 30500 bacteria/mL

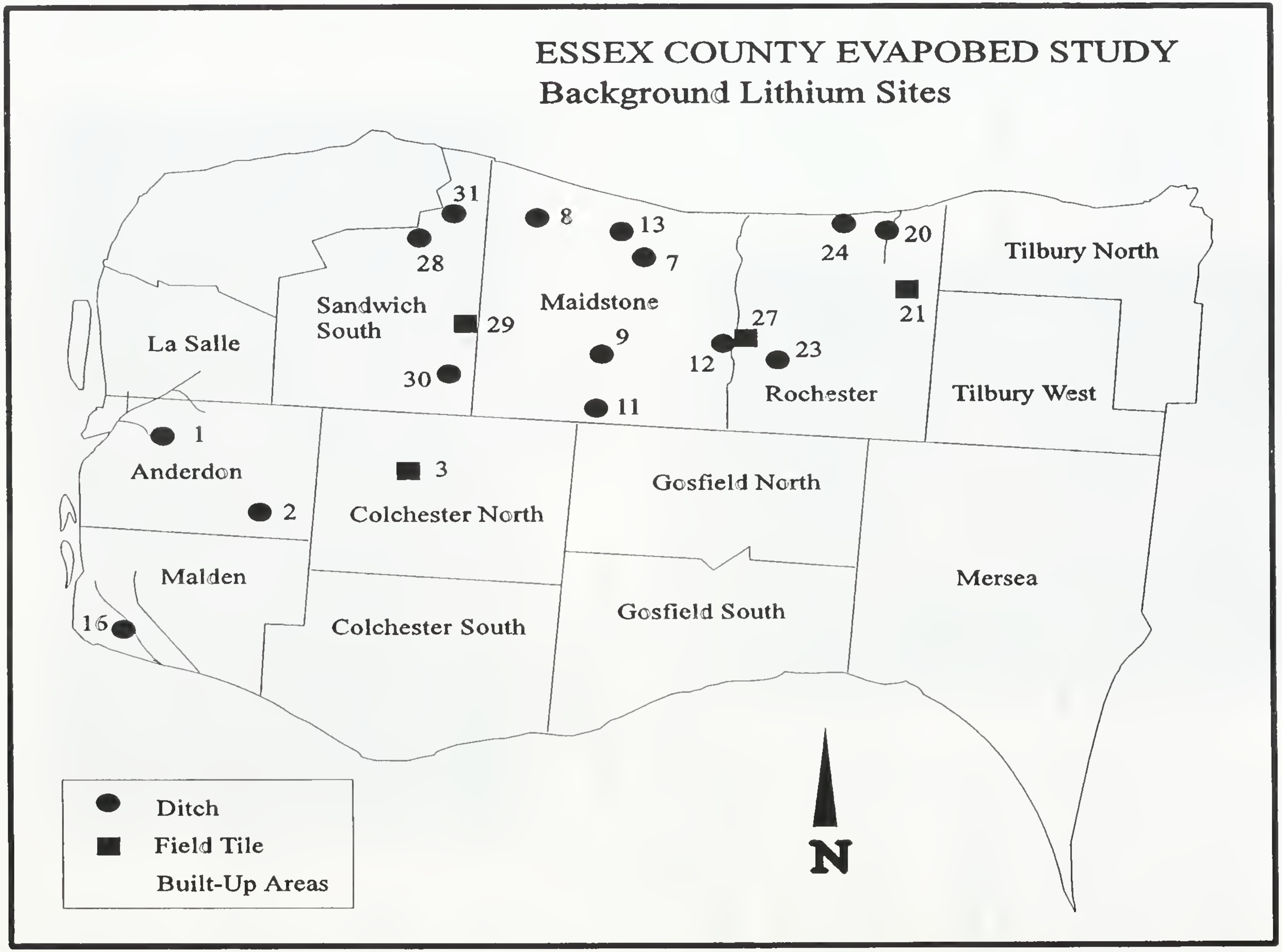


Fig. 6. Location of ditches and field tile drains used to determine regional background levels of Li in surface water.

3.5 Surface Water Sampling

Nutrient chemistry was analysed from piezometer samples collected on April 18-19, 1996 and compared to reference samples collected on May 13 from swales and tile drains adjacent to, but isolated from the study sites (Fig. 6). Nutrient chemistry was also compared against surface water samples collected in February and April, 1996 from several creeks in the vicinity. All nutrient analyses were conducted by staff of Laboratory Services Branch of MOEE using standard methods.

The criterion for significance of Li and water quality parameters in piezometers and surface water was chosen as a value exceeding one standard deviation above the mean of the sample set. Given the entire sample of water quality indicators, the mean value was that above which 50% of the sample lay. There was thus a 50% probability that a measurement equivalent to the mean represented reference water quality and a 50% chance that it represented a significant elevation. Values greater than one standard deviation above the mean imply a 32% probability that they do not represent a significant elevation (an environmental impact), given a standard two-tailed test. Detection of elevated water quality indicators represents, however, a one-tailed test, in which a cumulative normal probability curve is used (Sokal and Rohlf, 1973). One standard deviation encloses 83% of the cumulative probability function. Water quality measurements exceeding one standard deviation above the mean were therefore considered significant, as there was an 85% probability that they did not represent reference water quality.

3.6 Modelling an Evapotranspiration-Based Septic System

3.6.1 Purpose

The first purpose of the modelling exercise was to see whether or not the evapotranspiration rates for southwestern Ontario were sufficient to dispose of domestic sewage from a typical residence. The disposal requirement was a function of daily loading of effluent and precipitation to the system, as modified by the storage capacity of a typical installation. Although a second purpose had been to analyze model sensitivity - to determine how evapotranspiration variables changed within Ontario and hence the geographic restrictions on system performance, the fact that the model predicted failure even in Ontario's optimum evaporation climate precluded further analysis.

The model was based on the dimensions and construction of a standard evapotranspiration-based system (Fig. 1). A leaching bed of 3000 ft^2 (50' * 60'), is excavated to a depth of 10" in the native clay soil. Distribution pipes are installed on 5 foot centres in a bed of gravel so that their final grade is 10" above the native soil. Clean sand is placed between and over the pipes to a final grade of 19" above native soil. A 6" layer of topsoil (clay+sandy loam) over the top reduces rainwater infiltration and provides a medium for vegetation to grow. The mantle dimensions are 10' on each side and 50' in front of the leaching bed, excavated, as before, to a depth of 10". A 6" layer of clean sand and 4" layer of topsoil is placed and graded as level as possible to maximize the surface area available for evapotranspiration.

3.6.2 Principle of Model

Domestic sewage is stored within the soil pore spaces of the leaching bed and the mantle during periods of no evapotranspiration and is evaporated and transpired from the surfaces of the leaching field and the mantle during favourable climatic periods. Installation generally requires a commitment to water conservation from the user, to maximize the storage period in the leaching bed.

The form of the model was:

$$\mathrm{Vol}_t = \mathrm{Vol}_{t-1} + \mathrm{Load}_t,$$

where :

Vol = Volume of liquid in leaching bed plus mantle (litres)
Load = Loading of liquid to system (litres/day)

and :

$$\mathrm{Load}_t = (\mathrm{Eff}_L + P_L) - (E_a \text{ X } \mathrm{ET})$$

where :

Eff_L = Effluent load (litres/day)
P_L = Precipitation loading (litres/day) = P (mm/day) * Infiltration area
E_a = Evapotranspiration area (m^2) (= infiltration area)
ET = Evapotranspiration loss (mm/day)

The model operation set Vol_t as 0 on day 1 (Jan. 1 1961). Precipitation loads and effluent loads were added daily and evaporative losses subtracted. Days in which Vol_t exceeded the maximum capacity for storage in the leaching field plus mantle (56,600 L) were considered days of hydrologic surplus (=hydraulic failure) and days where Vol_t was less than the storage volume were acceptable. When a hydraulic failure was recorded, the model held Vol_t at the maximum until evapotranspiration reduced it again. This was done to prevent accumulation of an unrealistic surplus volume of effluent, under the understanding that water would seep out or run off to surface water courses in the event of hydraulic failure.

Two assumptions were made for the sake of simplicity and both would tend to overestimate the hydraulic capacity of an evapotranspiration-based system. First was that snowmelt was not added to the system as an hydraulic load. The second assumption was that the infiltration of precipitation to the system was a constant 70% of the recorded precipitation. This assumption is discussed below.

3.6.3 Terms of the Model

Total Potential Storage Volume : Effluent storage volume was calculated as the total, sand-filled volume of the leaching field plus the mantle. A typical evapotranspiration-based installation (Fig. 1) was used, in which the leaching bed dimensions were 35' by 90'. The mantle would add an additional 50' to the front and 10' to each side of the leaching field. Under most circumstances, effluent levels would remain below the distribution pipes and so total effluent depth is 10" within the leaching field. The system should theoretically be operational even with effluent levels above the distribution pipes, provided that effluent is below the outlet of the septic tank. Therefore, under standard, “worst-case” operating conditions, effluent would mound up to a depth of 4" over the distribution pipes, limited only by the 4" drop between the septic tank outlet and the leaching field. Any loading beyond that would result in failure of the system, and break-out and ponding of the effluent on the surface of the ground.

Total storage depth is therefore 10" + 3"(pipe diameter) + 4" = 17" within the leaching field. Total storage depth within the mantle is 6". The leaching field is filled with sand and so storage volume is limited by porosity of the sand. Calculations used a porosity of 30% which is typical for sands (T. Beukeboom, A. Campbell; pers. comm.).

Vol = (17" X 35' X 90') x 0.30 = (0.43m X 10.7m X 27.4m) X 0.30 = 37.8 m^3 = 37800 L within the leaching field

plus: (6"X35'X50')+(2X(6"X140'X10')) = (0.15m X 10.7m X 15.2m)+2X(0.15m X 42.7 X 3m) X 0.30 = 18.8 m^3 = 18,800 L within the mantle

Total = 37.8 + 18.8 = 56.6 m^3

This volume is sufficient to store 63 days of the average effluent loading observed in 1995, or 49 days of the high (mean plus one standard deviation) value used in the model.

Evaporative Surface area E_a: The total surface area of the leaching field (35' X 90') plus total surface area of the mantle ((35'X50') + 2(140'X10')) = 7700 square feet.

E_a = (10.7m X 27.4m) + ((10.7mX15.2m) + 2(42.7m X 3m)) = 712 m^2

Effluent Loading Function Eff_L: Actual hydraulic loading rates are uncertain and dependent on assumptions used. MOEE (1982) assume a daily load of 1600 L for a three bedroom residence for hydraulic considerations but a daily maximum of 1000 L/day per lot for nitrate contamination purposes (MOEE 1995).

For the model, two estimates of effluent loading were used. Actual water usage for 1995 for the 21 study homes for which water usage data were available ranged from 325 to 1339 L/day and mean usage was 869 L/day (std.dev. = 293; Table 2). The “average” loading scenario for the model used the 869 L/day figure, modified for seasonal variation. The “high loading” scenario was taken as the mean plus one standard deviation (= 1162 L/day) a value which included 17 of the 21 homes monitored and which is mid-way between the two standard MOEE estimates. The seasonal pattern of water use (Fig. 7) was not recorded from the study homes but was obtained from records of the Windsor office of MOEE and used to modify the measured annual average into seasonal estimates.

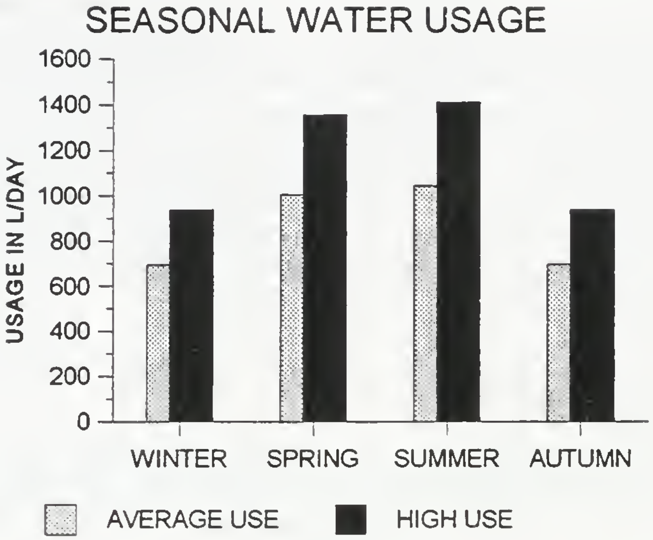


Fig. 7 Seasonal pattern of residential water use estimated for the modelling study.

Precipitation Loading (P_L): The depth of precipitation measured at the Windsor Airport was multiplied by the surface area of the leaching bed + mantle (= 712 m^2) to obtain the volume of precipitation loaded to the system. Thus, a 1 cm rainfall would add 7120 litres of water to the hydrologic budget. The infiltration of precipitation was set to zero in all cases where the ground was frozen (<0° C at the 5 cm depth, from measured records of the Harrow Agricultural station).

For periods when the ground was not frozen, infiltration of precipitation was modified by the runoff coefficient, which is dependent on soil type, slope and soil cover. Infiltration and runoff are complex phenomena, and the effects of these basic topographic elements are modified by duration and intensity of rainfall, soil moisture content and hydraulic conductivity. It was thus necessary to estimate an average infiltration coefficient. The Handbook on the Principles of Hydrology (Gray 1970) gives the following:

$c = 1 - (x+y+z)$, where

$c =$ proportion of a rain event which will run off
$x =$ coefficient of topography (= 0.30 for, flat land, slopes = 1 to 3 feet per mile),
$y =$ coefficient for soil type (= 0.20 for medium combinations of clay and loam, = 0.4 for open sandy loam). Choose 0.30 for clay loams mixed with sandy loam topsoil.
$z=$ coefficient for cover (= 0.10) for cultivated lands or lawns)

A runoff coefficient of 0.3 results, which produces an estimate of 70% for infiltration of rainwater into the leaching field. All precipitation loading to the leaching field was therefore reduced by 30% to account for runoff from the field surface.

Evapotranspiration ET: Evapotranspiration depth was modelled from the Penman-Monteith method (Monteith 1965). This method was chosen as it has been recognised as the best performing combination equation for estimating crop evapotranspiration (Pereira et al. 1995).

The Penman-Monteith equation estimates a latent heat flux from the vegetation surface. This heat flux can be translated to a measure of water evapotranspired to the atmosphere by multiplying the latent heat flux by the latent heat of vaporization of water.

$$\lambda E = \frac{\Delta(R_n - G) + \rho c_p[e_s(T_z) - e_z]/r_a}{\Delta + \gamma(1 + r_s/r_a)}$$

Where:

λE = latent heat flux from vegetation canopy (Wm^{-2})
Δ = rate of change of saturation water vapour pressure with temperature (mB)
R_n = net radiation (Wm^{-2})
G = soil heat flux (Wm^{-2})
ρ = density of dry air ($kg\ m^{-3}$)
c_p = specific heat of air at constant pressure
$e_s(T_z)$ = saturation vapour pressure at temperature T (mB)
e_z = vapour pressure at height z (mB)
r_a = aerodynamic resistance ($s\ m^{-1}$)
γ = psychrometric constant ($0.66\ mB\ K^{-1}$)
r_s = surface resistance ($s\ m^{-1}$) (from Monteith, 1965)

Two additional equations are required. The first of these estimates the aerodynamic resistance of the vegetation canopy. The second estimates the soil heat flux.

$$r_a = \frac{\ln(z-d)/z_o}{k^2 u}$$

Where:

z = height above ground (m) (0.01 m for a short grass canopy)
d = zero plane displacement (m) (set to zero)
z_o = roughness parameter (m) (from Monteith) 1965)
k = von Karman's constant (0.40)
u = wind speed ($m\ s^{-1}$)

and:

$$G=S_w\frac{T_s-T_a}{0.01}$$

where:

S_w = wet soil thermal conductivity ($Wm^{-1}\ K^{-1}$)
T_s = soil temperature (K)
T_a = air temperature (K)

The wet soil thermal conductivity value was for a clay soil with a 40% moisture content. This figure was taken from Oke (1978).

Meteorological records for the modelling exercise covered the period January 1, 1961 to Dec. 31 1995. Solar radiation values came from the Elora Agricultural Research Station (the closest site), relative humidity and wind records came from the Windsor Airport, and air and soil temperatures, precipitation, snow cover and hours of sunshine came from the Harrow Agricultural Research Station. The meteorological data are therefore considered representative of southwestern Ontario conditions.

Evapotranspiration was assumed to be zero for days of snow cover, and when the soil temperature was less than 0 degrees Celsius. Precipitation loading to the evapobed was assumed also to be zero when the ground was frozen (see above).

3.6.4. Other Factors

Pan Evaporation PE: Pan evaporation data are frequently cited in descriptions of evapotranspiration-based septic systems (Bernhart 1985). They were not used for the model as they are only available for the growing season. In addition, although pan evaporation estimates can be reliably related to actual evapotranspiration, the absolute values are often in error due to differences between advection and stored energy, conduction of heat through the pan itself and exposure conditions which are unrepresentative of regional climate, particularly the effects of wind (Viessman et al. 1972). Advection, in particular, has been cited as the primary reason pan evaporation estimates are unsatisfactory (Morton 1990). Conduction of heat through the pan itself would also bias measurements, producing greater variability in water temperature than would be expected in a large volume of soil.

As a result, pan evaporation data overestimate actual evapotranspiration. For example, the value of >1080 mm pan evaporation per year cited by Bernhart (1985) for the study area is 35% greater than the measured annual precipitation of 800 mm. (Fisheries and Environment Canada 1978). Adjusting the precipitation for the 200 mm of runoff measured annually produces an estimated annual evapotranspiration of 600mm. (Fisheries and Environment Canada 1978). Pan evaporation measurements of 1080 mm/yr are thus 80% higher than evapotranspiration for the study area, as derived from the actual water balance. This, plus the fact that pan evaporation data are not measured in winter invalidates their use in predicting annual losses of sewage effluent from evapotranspiration-based systems.

Infiltration: Infiltration of effluent into clay soils is possible but the rate is very slow. Faster rates are possible if the soil dries and cracks open in the bases of the mantle and the leaching field. Infiltration from these processes could not be properly estimated for inclusion in the model and so was set to zero. This assumption was considered valid on the basis of observation (in-ground septic systems fail in these soils) and on the standard practice of compacting soils underlying a evapotranspiration-based system prior to construction.

4.0 RESULTS AND DISCUSSION

4.1 User Survey

Due to the 1996 work interruption only 60 sites were subjected to the interview and inspection process. Of these, 4 sites were found to be experiencing problems with their systems. Two of the sites had used clay material to backfill their systems which sealed the surface and resulted in problems in the form of sewage breakout. One system had not been backfilled after eighteen months of use and the fourth system had been damaged by the installation of a storm swale and was discharging sewage. This system was used as a control for the Lithium and *E. coli* tracer studies.

In general the owners were co-operative and willing to participate in the survey. This suggested that they were not having problems with their systems. The four problems encountered during the survey were typical of bed failures investigated over the past seven years. Every investigation of failed systems has shown the failure to be the result of either improper cover material, poor surface water management, using the bed before the final top dressing and seeding was completed, damage to the installation or abnormally high water usage. In most instances repair was simple and inexpensive (G. Pillon, Windsor District Office, MOEE, pers. comm).

Water usage was less than that used for the various septic system approvals calculations (MOEE, 1982, 1995), suggesting that the water conservation measures dictated as a condition of system approval were being followed by homeowners. The average recorded water usage for the 30 sites was 861 L/day for 1995 and the range 325 to 1339 L/day (Table 2).

4.2 Lithium Tracer Study

4.2.1 Background Levels

Reference Li values were determined from tile drains in close proximity to 19 of the 30 test sites which were seeded with LiBr (Figs. 5,6). Reference values ranged from 1 to 14 µg/L (Table 5) and no geographic patterns in concentration were apparent across the study area. The arithmetic mean concentration for all sites was 6.50 µg/L (standard deviation = 3.12, Table 4). The criterion for significance of Li values measured in piezometers at the study sites was calculated as the mean reference site concentration plus 1 standard deviation, on the basis of a one-tailed test using a cumulative probability function (see Methods section). Any study sites at which Li exceeded 9.6 µg/L were therefore considered to be significantly elevated above regional background values and indicated an hydraulic connection between the septic system and the piezometer.

Table 4 Reference lithium concentrations measured in tile drains adjacent to study sites. All values in µg/L.

Site	**April 18, 1996**	**May 13, 1996**
1	6	
2	6	
3	6	
7	5	
8	1	4
9	6	
11	8	
12	8	
13	4	1
16	6	
20	9	7
21	3	
22		13
23	6	
24	8	9
28	6	
29	5	
30	5	
31	14	10

Mean = 6.50 Std. Dev. = 3.12 N = 24 Mean + 1 S.D. = 9.6

4.2.2. Lithium at Study Sites

Piezometers were visited 13 times between April 10 and May 18. Three sites were dry at every visit (Fig. 8) and two sites yielded water only once. Twenty eight of the 61 piezometers (19 of 31 sites) yielded water on more than half of the visits. All sites were inspected on May 22 and piezometers were dry. The study was therefore ended after the last samples had been collected on May 17.

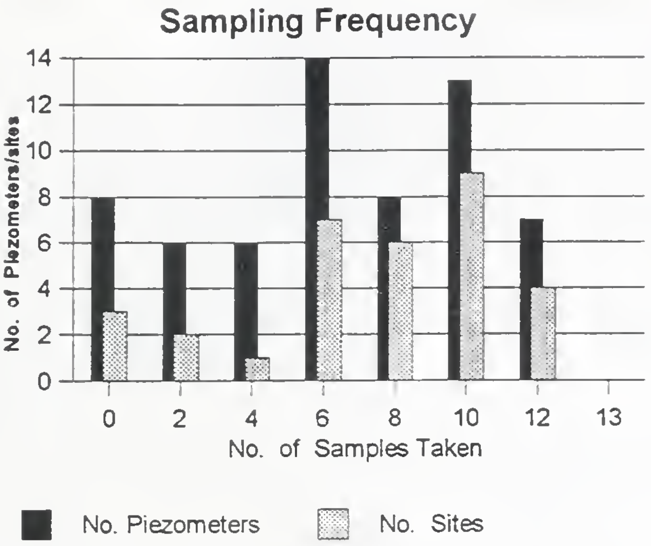


Fig. 8 Frequency of sample collection over 13 visits to 31 sites between April 10 and May 17, 1996. Samples were only collected when sufficient water was present in the piezometer.

Lithium concentrations were significantly elevated above reference values on at least one occasion in 30 of the 61 (49%) piezometers which were monitored, or at 17 of the 31 (55%) residences (Table 5). Of these, one piezometer at one house was installed in a system known to be failing because of disturbance, and was intended as a positive control on the method. One site (#8) was a system installed before 1993 at which no mantle was installed and another (Site 24) was completed in the autumn and was not yet grown over with grass. Lithium concentrations were significantly elevated above reference values for between 1 and 9 of the 13 sampling days at the various sites and maximum measured concentrations ranged from 13 to 227 µg/L. Lithium measurements thus suggested hydraulic connections between surface water and septic systems which were not known to be damaged at 47% (14/30) of the homes which were monitored. Hydraulic connection was observed at these sites on 8-69% of the sampling dates. On remaining visits piezometers were either dry, or samples had Li at concentrations below the detection criterion of 9.6 ug/L. Figure 9 shows several time series of Li concentrations in responding piezometers. Eight sites, including the three illustrated in Fig. 9 were redosed on May 13. Two of these showed subsequent increases in Li by May 17 when the study ended.

Systems responding to Li additions showed early peaks in concentration followed by steady declines over the course of the study but concentrations never reached expected levels of 1-2 mg/L in the piezometers. The two piezometers at each site did not respond in unison; showing either time lags or quantitatively different responses to the Li additions on April 2-4. This suggests that effluent flow was spatially variable, such that the major movement of Li was not captured by the two piezometers at each site. Effluent may also have been diluted by surface infiltration from the abundant rainfall recorded during the study.

Table 5 Summary of Li results at all sites where Li was detected at concentrations exceeding background. Number of days sampled indicates the number of the 13 visits when water was found in a piezometer and number of days of exceedance indicates the number of days (as % of 13 visits [] and as % of number of days which were sampled ()) when Li concentrations exceeded the regional background levels.

Site	**Piezometer**	**Maximum Li Value**	**No. Days sampled (% of total possible)**		**No. Days exceedance (% of total sampled) [% of total possible]**		
1	L	41	5	(38)	1	(20)	[8]
2	R	11	7	(54)	1	(14)	[8]
	L	16	9	(69)	4	(44)	[30]
3	R	11	8	(62)	3	(38)	[23]
	L	10	9	(69)	1	(11)	[8]
4	R	23	6	(46)	2	(34)	[15]
	L	30	4	(31)	1	(25)	[8]
7	R	10	7	(54)	2	(28)	[15]
	L	13	7	(54)	2	(28)	[25]
8	R	19	11	(85)	4	(36)	[31]
	L	227	11	(85)	6	(55)	[46]
9	R	20	6	(46)	2	(33)	[15]
	L	13	2	(15)	1	(50)	[8]
11	R	37	5	(38)	2	(40)	[15]
14	R	13	4	(31)	4	(100)	[31]
	L	15	9	(69)	1	(11)	[8]
17	R	11	8	(62)	1	(13)	[8]
	L	14	9	(69)	2	(22)	[15]
20	R	10	4	(31)	2	(50)	[15]
	L	14	9	(69)	2	(22)	[15]
22	R	14	11	(85)	1	(9)	[8]
	L	10	11	(85)	1	(9)	[8]
23	R	10	9	(69)	1	(11)	[8]
24	R	14	11	(85)	5	(45)	[38]
	L	14	9	(69)	9	(100)	[69
30	R	27	5	(38)	3	(60)	[23]
	L	152	8	(62)	3	(38)	[23]
31	R	11	6	(46)	1	(17)	[8]
	L	10	10	(77)	2	(20)	[15]
CONTROL		34	5	(83)	5	(100)	[38]

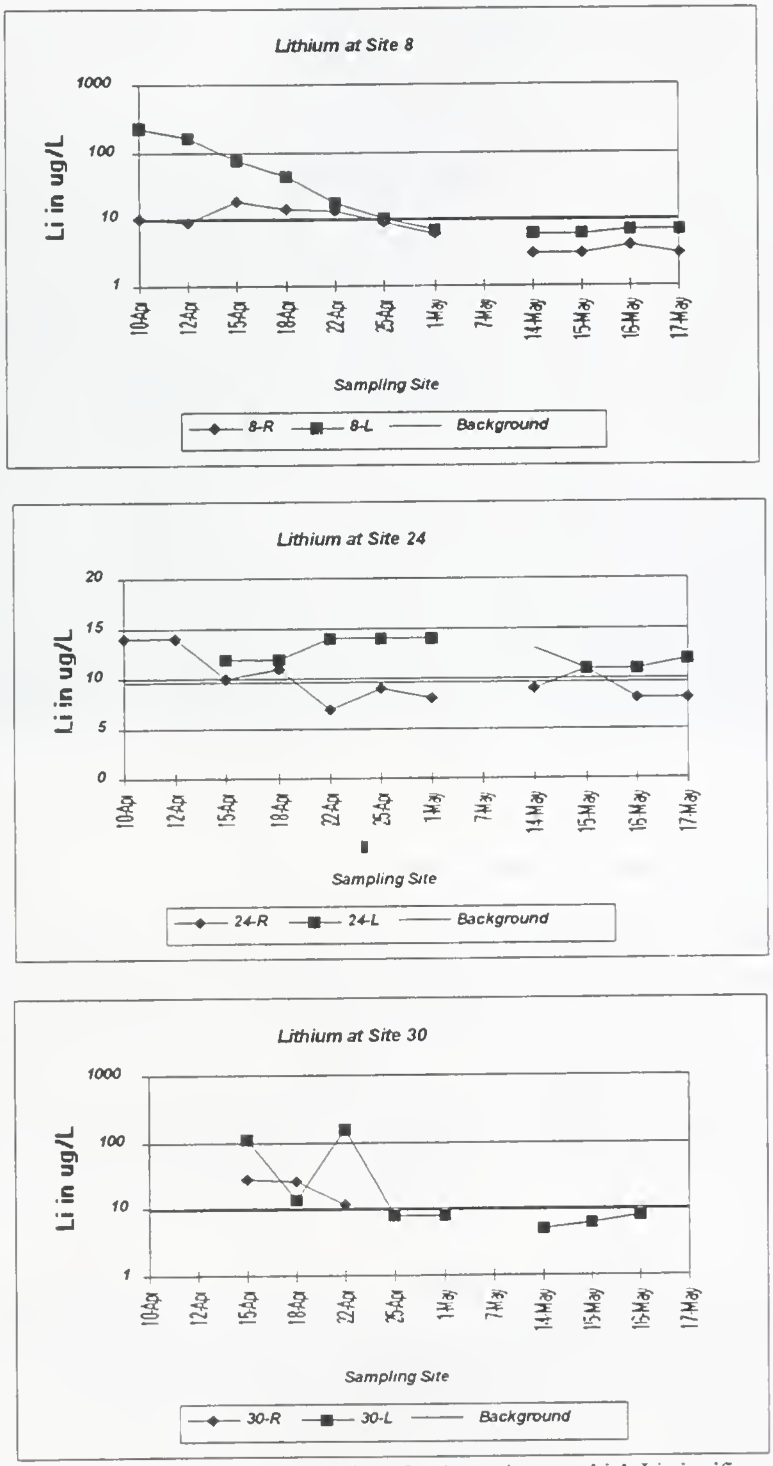


Fig. 9 Time series of Lithium concentrations for three sites at which Li significantly exceeded regional background levels.

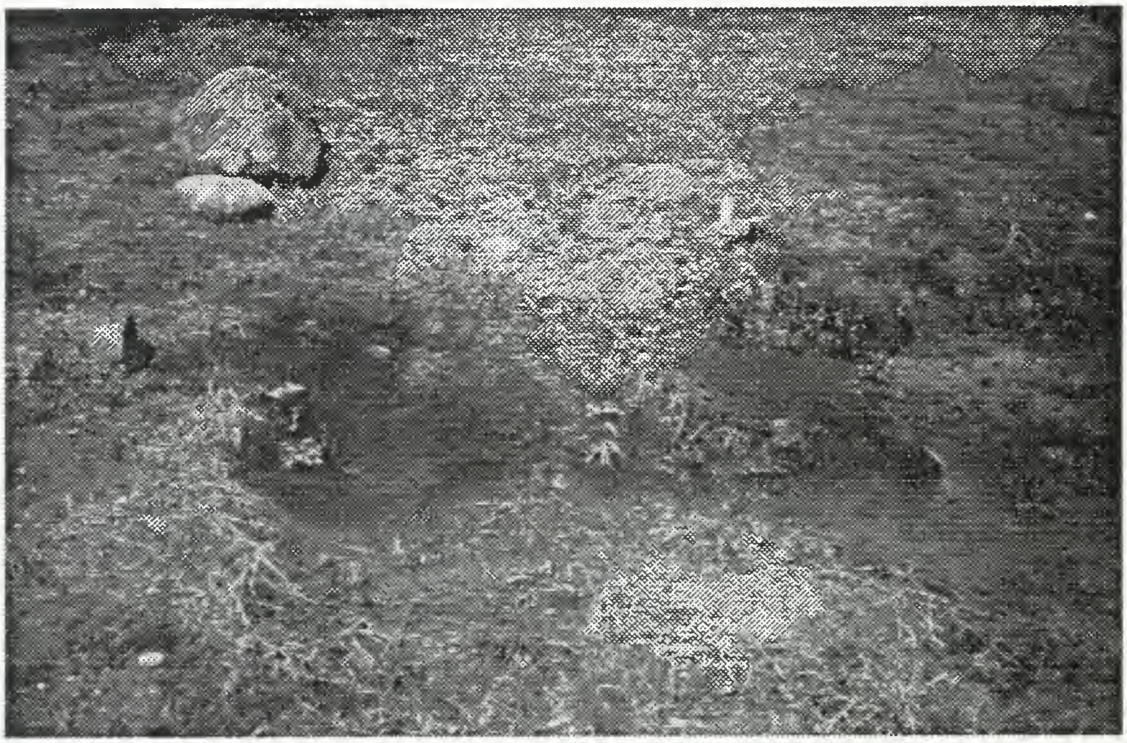


Fig. 10 Visible evidence of failure in a damaged evapotranspiration-based system which was used as a positive control in tracer studies. Piezometer is visible above and right of centre of photo.

4.2.3 Lithium in the Positive Control

Lithium bromide was dosed into a damaged system on April 26, 1996. The outer 3m of the mantle had been removed from one end by a bulldozer and visible breakout of sewage provided visible evidence that the system was failing. (Fig. 10). Low levels of Li were measured in the piezometer installed in the plume of leaking sewage. Concentrations of 34 µg/L were recorded 5 days after dosing and remained at 24-28 µg/L until the end of the study. (Fig.11). Although the Li tracer technique was adequate to produce a qualitative indication of system failure, the measured concentrations of Li did not provide as convincing evidence of failure as did the visible breakout.

Results from the positive control are convincing evidence that the Li response was not quantitative. All sites were dosed to achieve an expected concentration of 1-2 mg/L of Li at the point of piezometer installation, assuming even and complete dispersion. Whether dosed into the toilet, or directly into the tile field. Li concentrations in piezometers were lower than expected. Several factors may help to explain this response. First; overland runoff of effluent would not necessarily be captured in the piezometer, as it was sealed from surface infiltration with bentonite. Any Li detected within the piezometer would be a result of subsurface movement of effluent through the soil. Second, problems with incomplete mixing or uneven dispersion of Li within the tile field, or of channeling of effluent through preferential flow paths would produce a heterogenous distribution of Li. More piezometers would be required to increase the probability of detection in such a case. This is supported by detailed studies of septic systems, in which approximately 500 (Robertson 1995) or 50 piezometers (Wood 1993) were required to characterize movement of effluent plumes away from septic systems. Finally, although abundant rainfall during the study period could have diluted the effluent flow within the tile field by surface infiltration this is unlikely, given that final landscaping of an evapotranspiration-based septic system is intended to minimize infiltration of surface water.

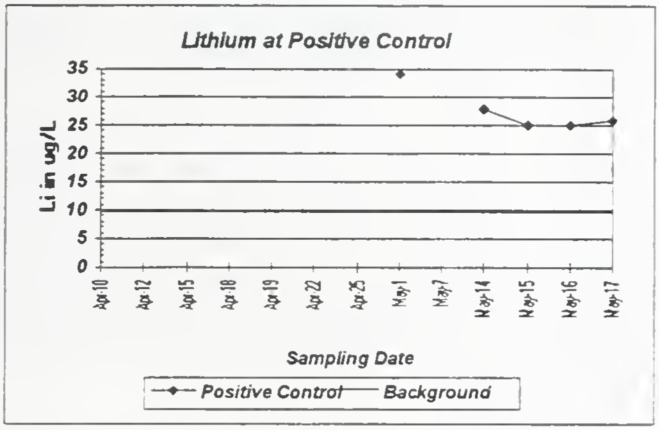


Fig. 11 Time series of Li concentrations at a damaged evapotranspiration-based system. Site was seeded with LiBr on April 26.

4.3.1 Tracer Bacteria in the Positive Control

Inoculation of the damaged system (the positive control) with tracer coliform bacteria produced much more convincing evidence of failure than the did the Li tracer (Fig. 12). Growth of bacteria was too dense to be counted between one and nine days after inoculation. Minimum counts (Most Probable Number per ml) of approximately 14000 were observed 9, 11 and 12 days after inoculation and values had increased ten-fold on the final day of the study. Coliform tracers at the positive control were much higher in relation to values measured in the nine undamaged systems than were Li concentrations in control and undamaged systems.

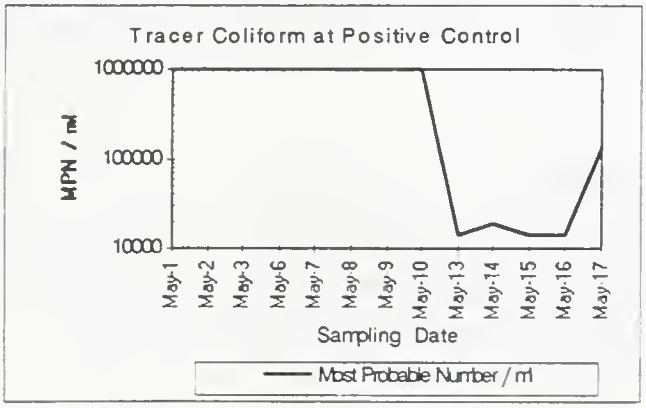


Fig. 12 Tracer coliform counts made at the edge of a damaged evapotranspiration-based system. Values above 100000 MPN could not be counted and are recorded as "Confluent Growth".

4.3.2 Tracer Bacteria at Study Sites

A total of nine systems, plus the one positive control, were inoculated with the tracer bacteria. Three sites were inoculated on each of April 23, April 30 and May 7, 1996 and all were monitored until May 17. The tracer bacteria were detected once at each of two sites (aside from the positive control) out of a total of 240 visits (piezometers * date * site). The first detection was at Site 24 (left piezometer) where 2 colonies were detected in 1 and 10 mL samples 8 days after seeding. The second detection was at Site 8 where 5 colonies were counted in a 10 mL piezometer sample 21 days after seeding.

These "detections" did not follow expected patterns of trend over time nor of number of colonies. The minimum count of colonies at the positive control site was 14000 and the maximum count at study sites was 5 colonies per ml. Tracer bacteria were only detected once at each of the two sites and did not show the expected pattern of build up and gradual decrease in numbers (see Fig. 12). Low counts and spotty detection strongly suggest that these counts were an artifact of sampling or analysis and therefore constitute false positives. They were not, therefore, considered as evidence of failure of these systems.

Only one sample from a swale sump showed contamination with tracer coliforms. At Site 8, 2300 colonies/ml were measured in the swale sump 15 days after their inoculation into the system. This site had shown elevated Li levels previously (Table 5, Fig. 9) but these had decreased to background levels at the time of coliform detection. The system at this site was built before 1993 and did not have a mantle installed.

Detection in the sump and not in the piezometer again suggests that effluent loss from the system was spatially heterogenous. The sump was installed as a spatial integrator of all effluent loss from the site, being in the furthest location downgradient. Detection of bacteria there confirms that the piezometers were not intercepting all of the effluent leaving the site, as bacteria should have been found in the piezometer as well as the sump. It is clear that installation of two piezometers per site was not sufficient to detect system failure. This is supported by detailed studies of septic systems, in which approximately 500 (Robertson 1995) or 50 piezometers (Wood 1993) were required to characterize movement of effluent plumes away from septic systems.

4.4 Surface Water Quality

4.4.1 Background Values

Background water quality was assessed in two ways. On May 15, surface water samples were taken from swales and tile drains adjacent to six of the study sites, but which were not hydraulically connected (Fig. 2). These results were used to calculate mean values and a criterion for detection of significant elevations of the same parameters in samples from piezometers taken on April 19. Any significant elevations were also compared with results from two samples of Turkey Creek and the Canard River which were taken by staff of Southwestern Region, MOEE in February and March, 1996 to determine if these elevations represented significant deviations from regional norms.

Table 6 Surface water chemistry from tile drains adjacent to study sites, May 15, 1996. All values used to represent "background" conditions except for Site 8. All concentrations in mg/L except for Li (ug/L).

SITE	NO2	NO2 + NO3	UN-IONIZED NH3	NH3 + NH4	TKN	PO4	TP	Li
13	0.085	2.90	0.003	0.15	1.90	0.12	0.30	1
20	0.160	4.15	0.014	0.75	1.55	0.02	0.04	7
22	0.375	0.85	0.012	0.65	1.85	0.06	0.14	13
24	0.030	11.1	0.001	0.05	0.5	0.02	0.02	9
31	0.005	0.05	0.003	0.15	0.55	0.02	0.02	10
MEAN	0.13	3.81	0.007	0.35	1.27	0.05	0.10	8.0
S.D.	0.15	4.39	0.006	0.32	0.69	0.04	0.12	4.47
MEAN + 1 SD	0.28	8.20	0.013	0.67	1.69	0.09	0.22	12.5
8	0.075	0.20	0.256	14.20	16.70	2.52	2.70	4

The sample from site 8 came from a tile drain across the road from the study site. High levels of ammonia, Kjeldahl nitrogen, phosphate and total phosphorus in this sample are all indicative of nutrient contamination. The forms of nitrogen present, plus observations that the sample smelled of sewage (K. Cincurak, pers. comm.), suggest that sewage, rather than fertilizer runoff was the source of the nutrient contamination. Ammonium is readily adsorbed by soils, so that any surface runoff of nitrogen from fertilizer application would occur as organic nitrogen in association with eroded soil. Losses of nitrogen to subsurface water occur as nitrate (Walker and Branham 1992). The composition of sample 8 (14.2 mg/L ammonia + ammonium, 2.5 mg/L organic N and 0.20 mg/L NO_2 + NO_3) is not consistent with the expected composition of fertilizer runoff. These results were therefore were therefore considered as a representative signature for domestic sewage in the piezometer samples.

The criterion for significant elevation of piezometer samples above background water quality was, as in previous comparisons, one standard deviation greater than the mean value for each parameter. Un-ionized ammonia concentrations were calculated as 1.8% of total ammonia+ammonium concentrations, assuming a temperature of 10°C and pH 8.0 (MOEE, 1994).

Table 7. Water quality of piezometer water collected on April 19, 1996. Bold-face type denotes those values which were significantly higher than mean regional background values. **** indicates no measurement.

SITE	NO2	NO2+NO3	NH3+NH4	UN-IONIZED NH3	TKN	PO4	TP	Li
7R	**0.58**	0.80	**1.35**	**0.024**	**2.95**	0.02	0.04	8
7L	0.09	1.15	**0.95**	**0.017**	**2.30**	0.02	0.04	11
8R	**0.85**	0.40	0.30	0.005	1.55	0.02	0.04	**14**
8L	0.05	0.10	0.05	0.001	0.60	0.02	0.02	**44**
12R	0.1	0.75	**1.00**	**0.018**	**2.80**	0.02	0.08	9
12L	0.035	0.45	0.15	0.003	**1.70**	0.02	0.04	7
13R	0.02	0.5	0.15	0.003	1.30	0.02	0.02	3
13L	0.015	0.5	0.05	0.001	0.85	0.02	0.02	3
14L	0.005	3.9	**5.7**	**0.103**	**6.4**	0.06	****	6
15R	0.015	****	0.05	0.001	0.85	0.04	****	8
15L	0.015	**16.2**	0.05	0.001	0.75	0.06	0.04	5
16R	0.02	0.4	0.45	0.008	0.85	0.02	0.02	3
16L	0.06	0.75	**0.7**	**0.013**	1.55	0.02	0.02	4
17R	0.02	0.6	0.1	0.002	1.05	0.02	0.06	4
17L	0.005	0.55	0.05	0.001	0.6	0.02	0.04	7
20L	**0.415**	1.8	**2.6**	**0.047**	**8.25**	0.02	0.16	10
21R	0.03	1.8	0.1	0.002	**2.05**	0.02	0.02	7
21L	0.26	2.3	**1.9**	**0.034**	****	0.02	0.02	6
22R	0.015	1	0.3	0.005	**2.25**	0.02	0.08	12
22L	0.005	0.05	0.05	0.001	0.55	0.02	0.02	10
23R	0.030	0.3	0.3	0.005	0.25	****	0.10	10
24R	0.02	0.55	0.05	0.001	1.1	0.02	0.04	11
24L	0.03	3.3	0.15	0.003	**2.3**	0.04	0.12	12
26R	0.085	3	0.1	0.002	0.6	0.02	0.02	4
26L	0.015	0.05	0.05	0.001	0.3	0.02	0.02	7
27L	0.02	0.3	0.2	0.004	0.55	0.02	0.02	7
29R	0.12	6.55	0.15	0.003	0.95	0.04	0.08	5
29L	**0.5**	3.6	0.25	0.005	1.05	**0.28**	**0.38**	5
30R	0.02	3..85	0.05	0.001	**1.9**	0.06	**0.64**	**26**
30L	0.015	2.65	0.1	0.002	0.95	0.02	0.08	**13**
31R	0.030	0.25	0.05	0.001	1.15	0.04	0.16	8
31L	0.005	0.15	0.25	0.005	1.4	0.02	0.04	7

Table 8 Comparisons of piezometer water quality with several criteria for significant elevation or impairment. All concentrations are in mg/L except for Li (ug/L). "NA" denotes those parameters for which no PWQO exists and "NC" denotes no comparison because of differences in pH and temperature between times of sample collection in local streams and in piezometers.

	NO2	**NO2+NO3**	**NH3+NH4**	**UN-IONIZED NH3**	**TKN**	**PO4**	**TP**	**Li**
REGIONAL SURFACE WATER BACKGROUND FROM TILE DRAINS								
	0.28	8.2	0.67	0.013	1.69	0.09	0.22	12.5
Number of Sites Significantly Elevated								
	4	1	7	7	10	1	2	4
Maximum Measured Concentrations								
	0.580	16.2	5.7	0.103	29.7	0.28	0.64	44
PROVINCIAL WATER QUALITY OBJECTIVES								
	N/A	N/A	N/A	0.020	N/A	0.03	0.03	N/A
Number of Sites Exceeding PWQO								
	N/A	N/A	N/A	4	N/A	8	12	N/A
WATER QUALITY OF LOCAL STREAMS (FEB-MAR 1996)								
	0.150	4.85	0.51	0.002	1.88	0.12	N/A	N/A
Mean + 1 SD								
	0.22	7.68	0.69	N/A	2.49	0.23	N/A	N/A
Number of Sites Exceeding Local Stream Water Quality								
	5	1	6	N/A	4	0	N/A	N/A

4.4.2 Surface Water Quality

Water samples taken from piezometers showed that treated sewage effluent was moving beyond the margins of the septic systems. Elevated Li levels at sites 8 and 30 on April 19 (Table 7) confirmed an hydraulic connection to the septic systems on that date but Site 8 was a system which had been installed with no mantle prior to 1993. Elevated concentrations of total phosphorus (0.64 mg/L) and Kjeldahl nitrogen at site 30R and nitrite at Site 8 showed that water quality was impaired compared to that of adjacent surface water or the PWQO for total phosphorus at Site 30. Piezometers at Sites 7, 12, 14, 16, 20, 21, 22, 24 and 30 all showed concentrations of ammonia, nitrate and Kjeldahl nitrogen which were significantly above those measured in adjacent surface water (Table 7) and regional streams (Table 8). Lithium concentrations at sites 7, 14, 20, 22, 24 and 30 had been significantly elevated during the tracer study (Table 5) and so water quality impairment could be considered a result of effluent loss from the septic systems at these sites. The concentrations of un-ionized ammonia were estimated for a temperature of 10 degrees and a pH of 8.0 and were above the PWQO of 0.020 µg/L at four sites (Table 8). Total phosphorus values were above the PWQO of 0.030 for running waters at 18 of the 32 sites but most of these exceedances represent high regional values as only 2 (29L and 30R) exceeded the regional criterion of 0.22 mg/L for significant elevation (Table 6). Site 30 had previously shown high levels of Li (Fig. 9). In summary, losses of effluent from properly operated evapotranspiration-based systems were a likely cause of impaired water quality at 10 separate sites on the one date that measurements were made. Further measurements and more detailed instrumentation (more piezometers per site) are highly recomended in any further studies.

Water quality measurements made within piezometers were compared to the results of an MOEE survey of 2 regional streams made on Feb. 13, 1996, the best comparisons available (Table 8). The same sites which were impaired compared to the tile drain data were also elevated in comparison to regional surface water quality. As before; nitrite, nitrate, ammonia and Kjeldahl nitrogen values were all elevated and consistent with an interpretation of domestic sewage contamination.

4.5 Summary of Monitoring Studies:

Hydraulic connection of evapotranspiration-based septic systems with adjacent surface waters was demonstrated by Li tracer techniques at 14 sites which were not known to be damaged or improperly constructed (Table 9). Nutrient levels in piezometers were significantly higher than those in adjacent surface waters at 10 sites where systems were not known to be damaged or improperly constructed (Table 9). Only six sites, however, showed both hydraulic connection (Li) and impaired water quality; sufficient evidence to conclude that water quality impairment was a direct consequence of the failure of the septic systems. The apparent low degree of congruence between the two methods must also, however, consider the minimal survey design of only two piezometers per site (Robertson 1995, Wood 1993), one collection of water quality and poor performance of the Li tracer, even at the positive control site.

Combining evidence from the Li and water quality studies, and removing systems known to be damaged or improperly built from consideration, leaves a total of 19 sites of 29 (66%) at which there was evidence that evapotranspiration-based septic systems did not perform properly and were likely to have impaired local surface water quality. This proportion suggests that over 1100 of the 1800 evapotranspiration-based systems installed in Essex and Kent Counties could be failing in the early spring period.

Although this number is high, it must also be considered against the severity of the environmental impact. No leakage of bacteria to the environment was detected in any properly built system and so human health impacts are unlikely. The toxic, un-ionized proportion of ammonia only exceeded the PWQO of 20 µg/L at four sites. This PWQO is intended to protect aquatic life but the receiving waters immediately adjacent to the study sites (swales and ditches) could not reasonably be considered as good quality aquatic habitat, due to the impacts of agricultural practices on surface waters. Agricultural runoff is considered the major source of nutrients (phosphorus) and eroded soils to surface water in this region (O'Neill, 1992).

Nevertheless, a minimal study design produced evidence that 2/3 of the systems are impairing environmental quality in some fashion. Proper instrumentation (more piezometers), more sampling effort and a longer and earlier monitoring period must all be considered as factors which would change the results reported here. The fact that these systems are used in rural areas prevents the high density of installations which could create problems with repetitive and cumulative losses of effluent to the environment.

Table 9 Comparison of results of four monitoring techniques employed in the study.

Survey Type	No.of Sites Impaired	Site I.D.	Comments
Inspection/Interview	4 of 60	confidential	All failures due to improper construction or maintenance
Lithium	17 of 30	1, 2, 3, 4, 7, 8, 9, 11, 14, 17, 20, 22, 23, 24, 30 , 31, control	Site 8 - no mantle, vehicle traffic(?) Site 24 - not vegetated Control - damaged
Tracer Bacteria			
- piezometer	1/9	control	damaged
- swale sump	1/9	8	Site 8 - no mantle, vehicle traffic(?) control - no swale sump installed
Water Quality			
- tile drains	12	7,8,12,14,15,16,20, 21,22,24,29,30	all with high nitrogen, 29 & 30 had high TP as well Site 8 - no mantle, vehicle traffic(?) Site 24 - not vegetated
- PWQO	4	7, 14, 20, 21	does not include 19 sites exceeding PWQO for TP
- streams	6	7,12,14,16,20,21	nitrogen higher than streams in area
Summary	19	1,2,3,4,7,9,11,12,14, 15,16,17,20,21,22,23 29,30,31	19 sites showed evidence of failure or impairment of adjacent waters and were not known to be improperly built or maintained.
	6	7, 14, 20, 22, 24, 30	6 sites showed loss of Li and impairment of adjacent waters. Site 24 was not vegetated.

4.6 Evaporation Modelling

4.6.1 Corrections for Soil and Snow

The evaporation model was run in two configurations. In the first, evaporation estimates were generated from theoretical models of potential evapotranspiration (Monteith 1965) with no correction for soil temperature or snow cover. Annual evaporation totals ranged from 786 to 918 mm/year (mean = 840) for the 1961 to 1995 study period. Filters were then applied to the model which set evaporation (and infiltration of precipitation) to zero on days in which soil temperature was below zero or when snow cover was present. This corrected model reduced the annual evaporation totals to a new range of 723 to 874 mm/yr (mean = 789) for the study period. The filters were considered appropriate modifications because a) snow cover would prevent evaporation of water from the soil surface and b) frozen soil would prevent the translocation of water to the soil surface and so effluent water would not be available for evaporation. The corrected estimate was only slightly higher than the range of 600 - 700 mm annual evaporation reported for southwestern Ontario in the Canadian Hydrological Atlas (Fisheries and Environment Canada, 1978) and was therefore considered valid.

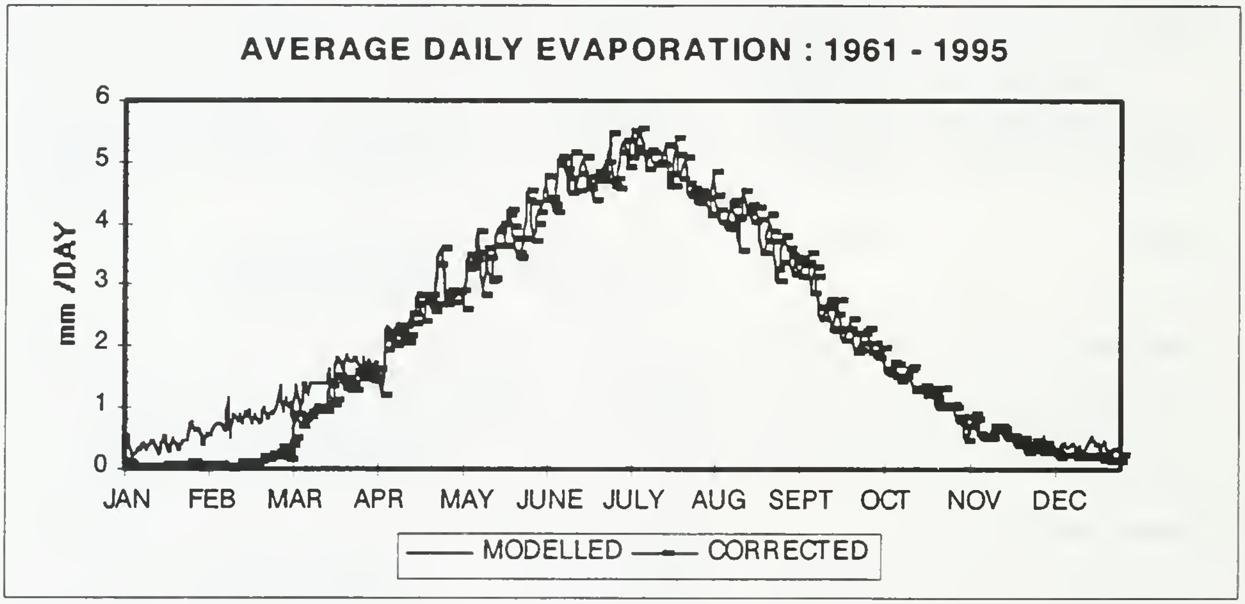


Fig. 13 The 34 year daily average evaporation for the study area (in mm) calculated by two separate methods. "Model Estimate" was calculated as total evaporation from meteorological observations. "Corrected" evaporation was adjusted to zero for days of snow cover or where soil temperature was below zero.

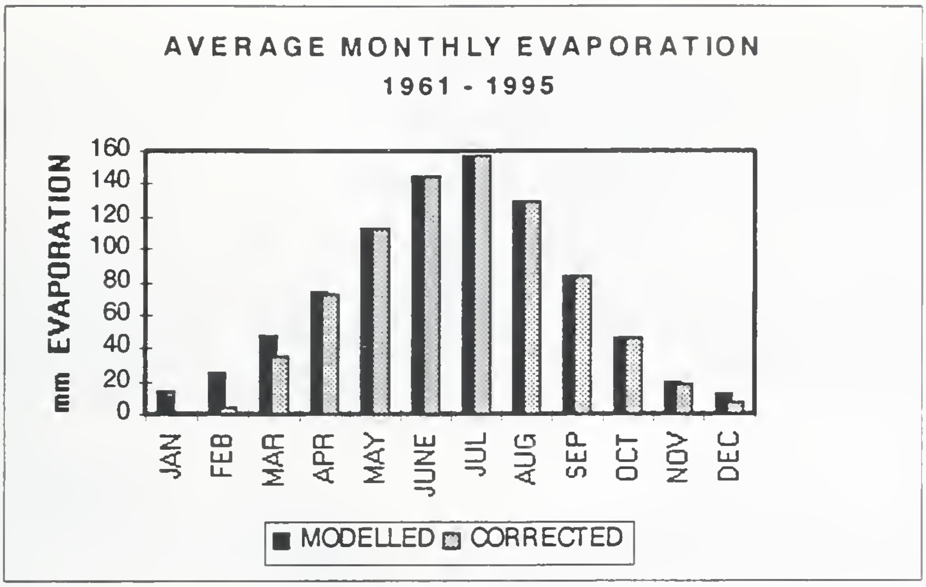


Fig. 14 The 34 year average monthly evaporation for the study area (in mm) calculated by two separate methods. "Modelled" was calculated as total evaporation from meteorological observations. "Corrected" evaporation was adjusted to zero for days of snow cover or where soil temperature was below zero.

The two estimates of daily evaporation were each averaged for the 34-year study period. Total modelled evaporation averaged 2.30 mm/day and ranged from 0.18 mm in early January to 5.53 mm in early July (Fig. 13). Correction of the modelled estimates for periods of snow cover and frozen ground dropped the minimum value to 0.015 mm but had no effect on the maximum. Average daily corrected evaporation was 2.16 mm/day over the study period.

Average modelled monthly evaporation was 72 mm over the study period and ranged from 12.2 mm in December to 447 mm in July before correction (Fig. 14). Correction for snow cover and frozen ground reduced the monthly average to 68 from 72 mm and winter evaporation estimates from 12.2, 13.6, 24.5 and 46.9 for December, January, February and March, respectively, to 1.8, 3.6, 34.7 and 72.6 mm..

4.6.2 Full Model of Evapotranspiration-based System

Hydrologic surplus (or "hydraulic failure") of the evapotranspiration-based system was defined as any day in which total effluent volume exceeded the storage capacity of the tile field plus mantle (=58800 L). In these cases, effluent would be expected to move horizontally out of the system, seep from the edges and move to the nearest surface water. Evapotranspiration rates, although substantial between April and December, were not sufficient to balance the annual hydrologic budgets of systems receiving either average loads of effluent (=869 L/day) or higher loads of 1162 L/day.

Regardless of whether the high or average effluent loading functions were used, the evapotranspiration-based system was predicted to have a net hydrologic surplus between early September and early April (Fig15, top panel). The average daily hydrologic surplus was 1.02 mm under high effluent load and 0.60 mm under the average effluent load. Although the volume of effluent supplied to the system influenced the volume of hydrologic surplus of the system, it had little influence on the duration, as shown in Fig. 15, bottom panel. The 34 year average shown in Fig. 15 includes all extremes of loading. In any given year, however, the duration of hydrologic surplus was generally shorter than the long-term average.

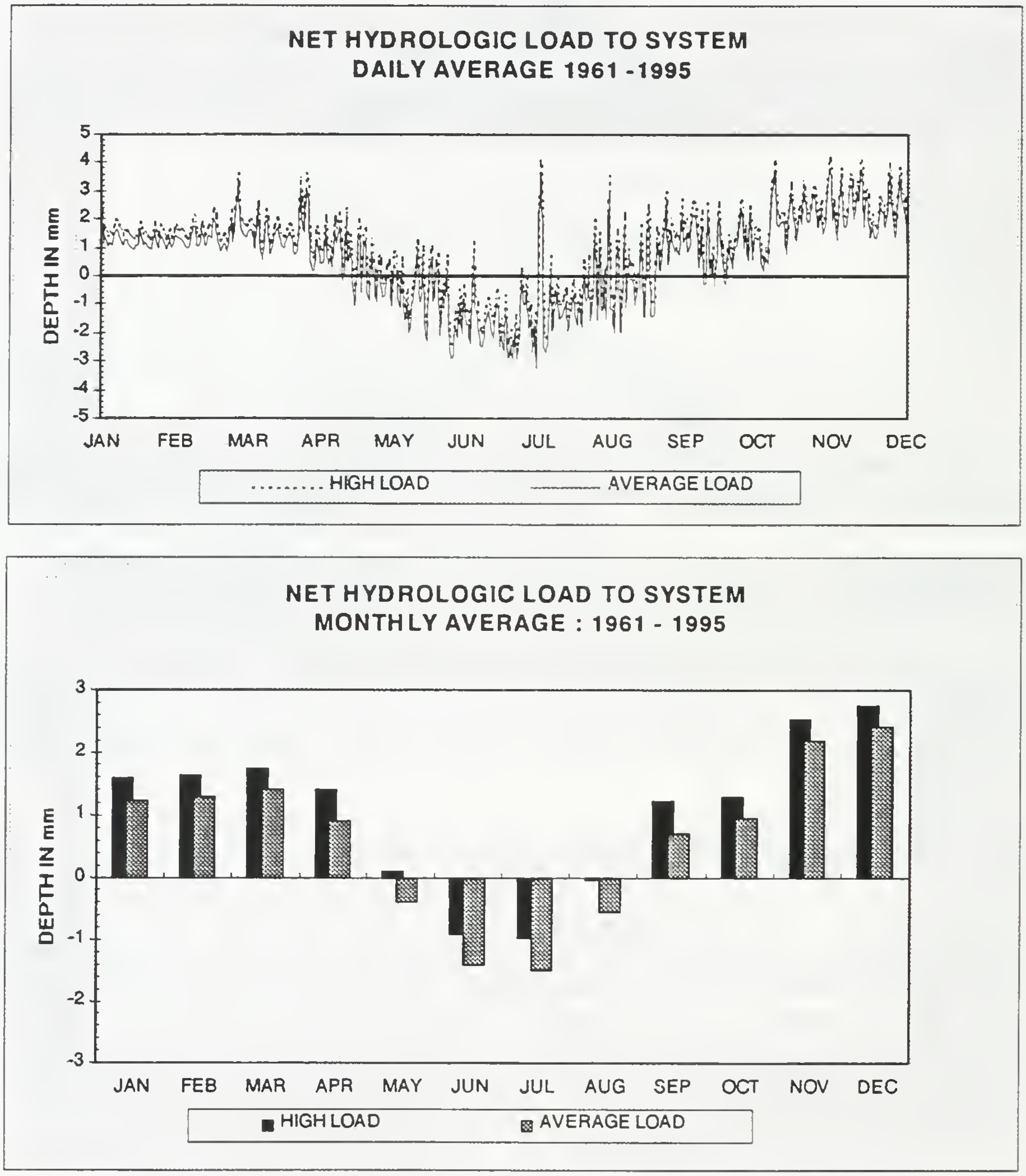


Fig. 15 Hydrologic budgets for a modelled evapotranspiration-based system showing average net hydrologic loadings for daily (top) and monthly (bottom) periods from 1961 to 1995. Net loadings (as depth in mm) are the difference between loadings from effluent plus precipitation, minus evapotranspiration losses.

Between May and September, evapotranspiration was sufficient to remove all hydrologic loadings (precipitation plus effluent) to the system. Although the daily evapotranspiration averaged 2.16 mm on an annual basis, it was less than the effluent loading alone from November to March under both high (1.63 mm) and average (1.21 mm) effluent loads (Fig. 16) and so the model predicted a hydrologic surplus to the septic system. Infiltration of precipitation into the tile field and mantle added substantial quantities of water to the system in all months except January and February (Fig. 16). Precipitation did not, however, contribute substantially to the overall hydrologic surplus. Precipitation loadings alone were sufficient to cause hydrologic surpluses only in October, under both high and average effluent loads (Fig. 16). The average monthly hydrologic surplus was 1.01 mm/day under high effluent loading and 0.59 mm/day under average loading.

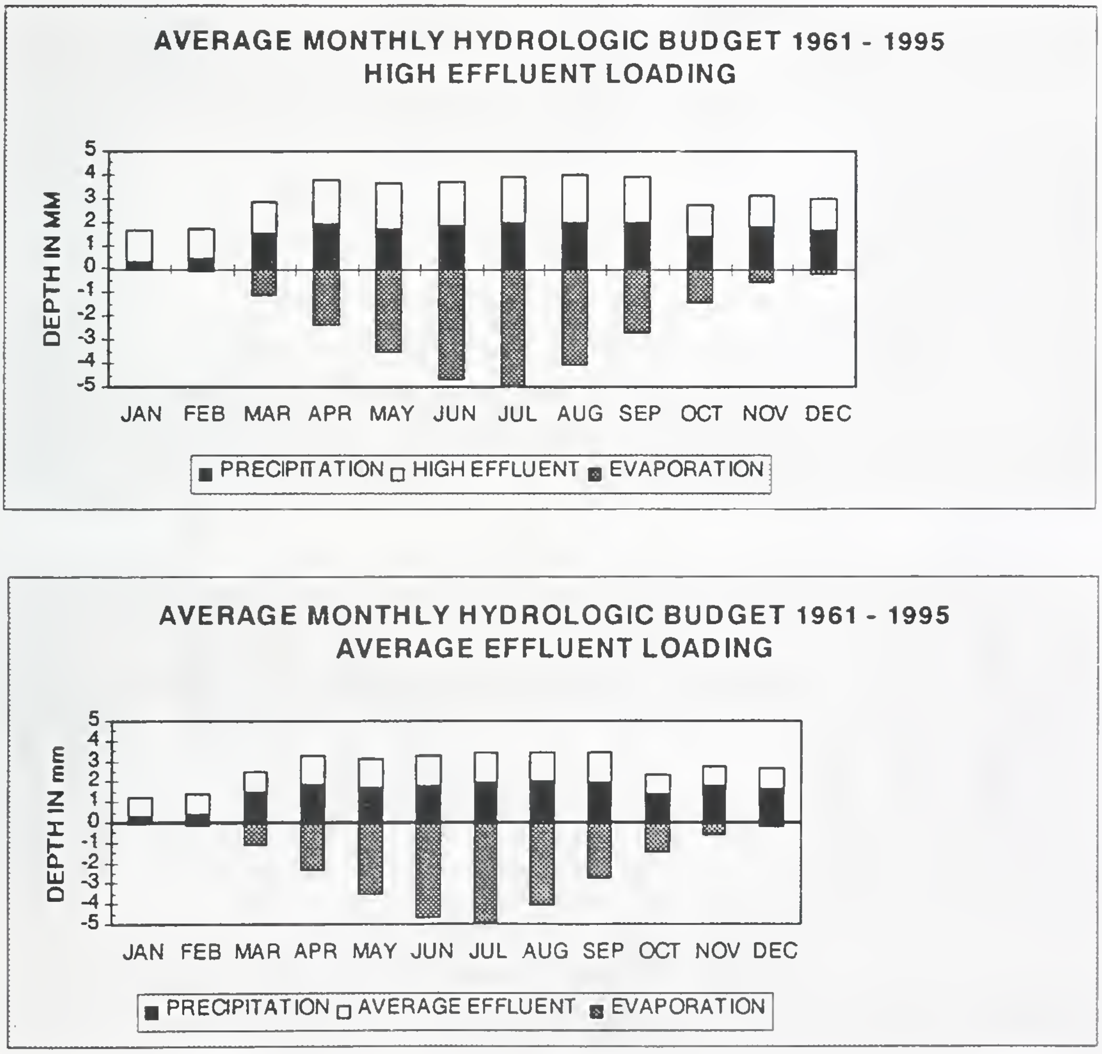


Fig. 16 Net hydrologic budget for an evapotranspiration-based system showing average monthly loadings from effluent (high loading at top, average loading at bottom) and precipitation compared to average monthly evapotranspiration losses.

The model mirrored the performance expected of an evapotranspiration-based septic system. Total stored volume was high in winter, the system gradually emptied between April and July and began to refill in September (Fig. 17). Under actual conditions, excess loadings would be lost to the environment from the system once total volume exceeded 58,800 L (tile field plus mantle storage) until such time as evapotranspiration increased again. The total storage volume was therefore capped at 58,800 L in the model. Note that the daily averages over 34 years showed many more days of residual storage volume than would be expected in any given year and never showed a system which was totally empty. This is an artifact of a long study period, encompassing climatic extremes and their influences on evapotranspiration and precipitation.

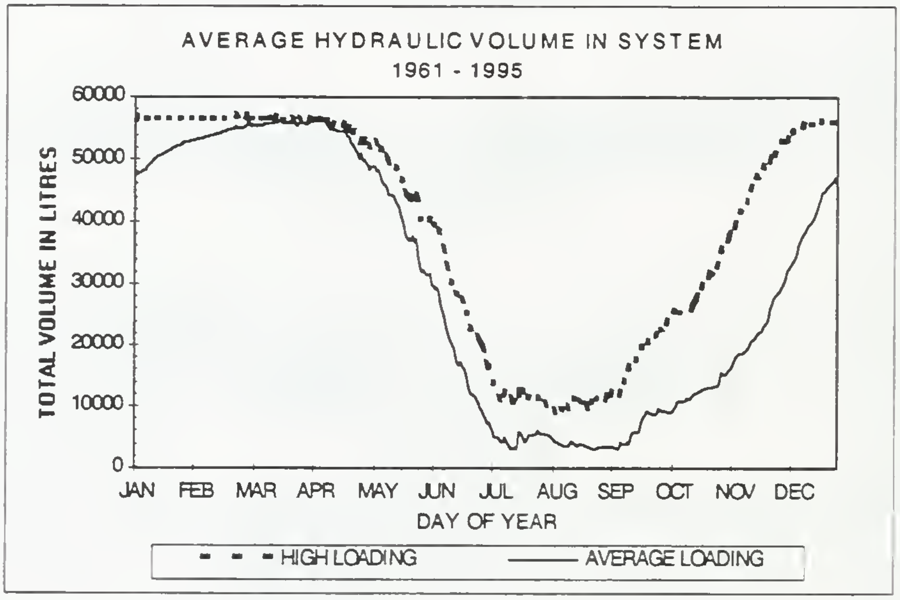


Fig. 17 Daily hydrologic storage (volume of effluent plus precipitation) in an evapotranspiration-based system, averaged over a 34 year simulation. Storage volume was capped at 58,800 L (the system capacity) when predicted storage exceeded 58,800 L.

System performance was also assessed by examining the number of days of hydrologic surplus predicted in each year of the simulation (Fig. 18, top). On average, systems were overloaded for 102 days and 155 days per year under average and high effluent loadings, respectively. In the best years, systems were overloaded for 24 days (average load, 1964) or 104 days (high load, 1971). In the worst year (1980), the model predicted overload for 199 days (average load) or 221 days (high load). These estimates did not include the first year of the simulation, 1961, as the model started on January 1 and required time to fill the storage volume in the first year.

Hydrologic surpluses were predicted, on average, for all of December and January (Fig. 18, bottom) under high effluent loads. With average effluent loads, hydrologic surpluses were predicted for 17 days of December, on average, and for 23 days in January. Any hydrologic surpluses between May and September were attributed to large precipitation events.

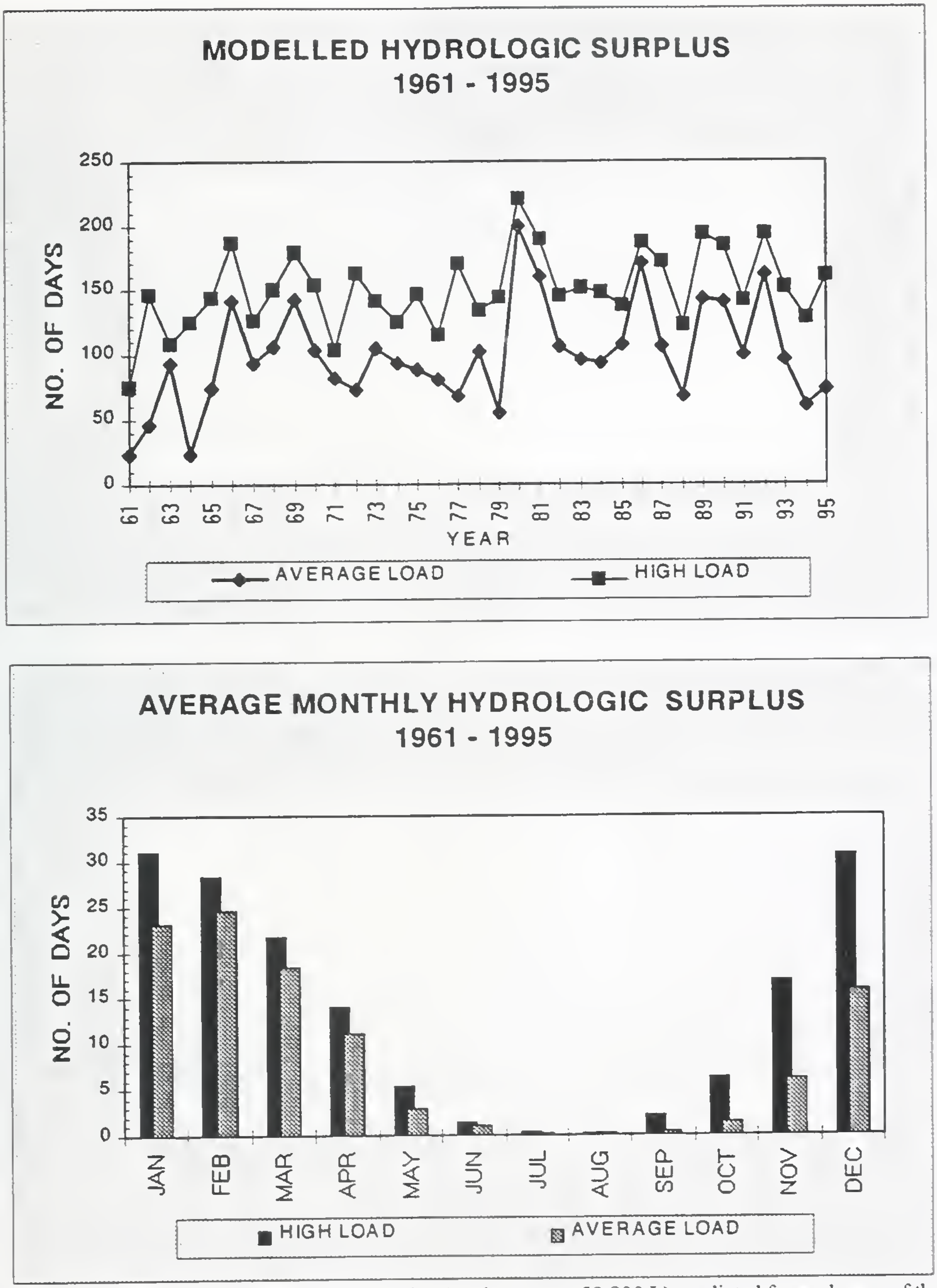
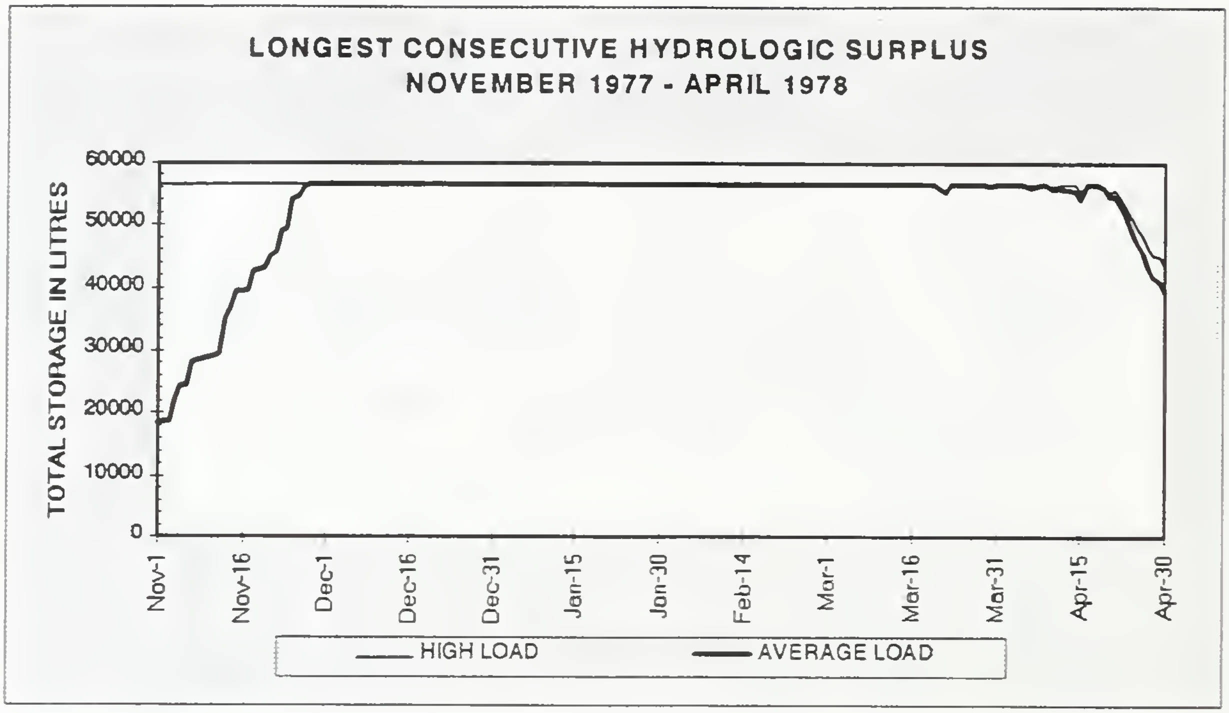


Fig. 18 Number of days of hydrologic surplus (total storage >58,800 L) predicted for each year of the 1961-1995 study period (top panel) and average number of days of hydrologic surplus per month (bottom). Conditions were modelled for high (1139 L/day) and average (869 L/day) effluent loads.



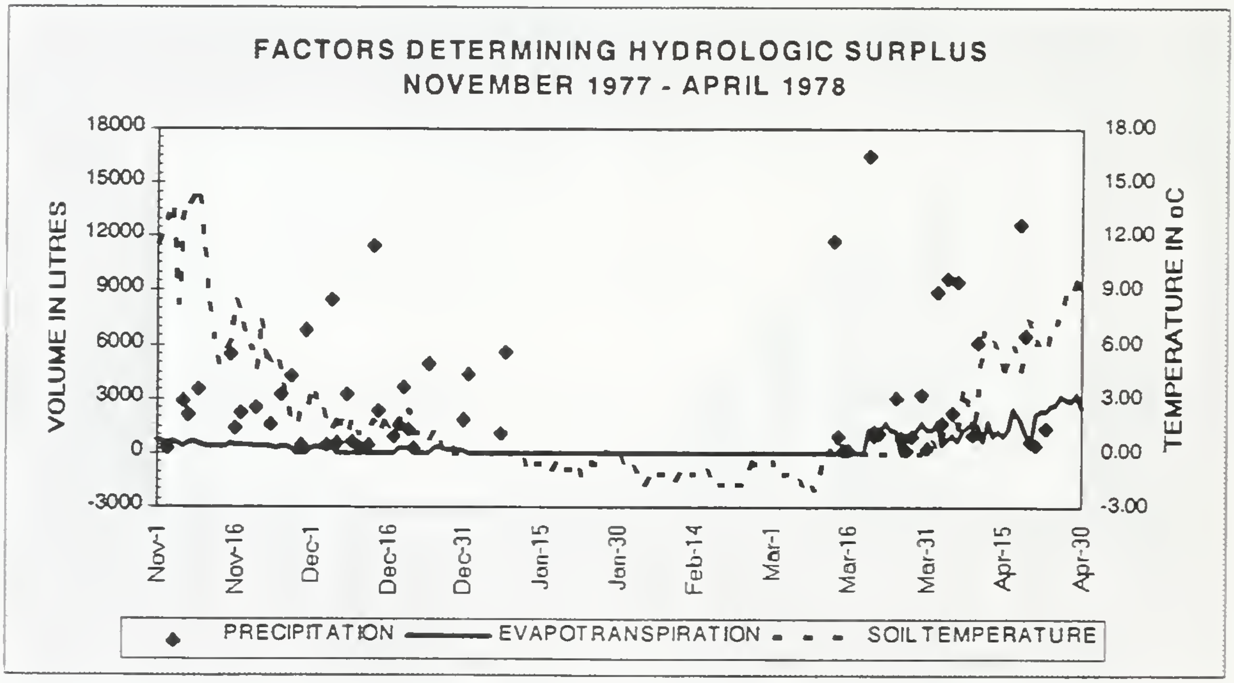


Figure 19. Climatic factors influencing performance of a modelled, evapotranspiration-based septic system.

Predicted evapotranspiration was minimal during winter months but soil temperature was also an important factor restricting function of the system. Evapotranspiration was set to zero when soil temperature was below zero at the 5 cm depth, as frozen soils would prevent translocation of water to the surface, even in the absence of snow cover. Freezing soil temperatures prevented evapotranspiration during the longest predicted hydrologic surplus between late December 1977 and mid-March 1978 (Fig. 19, bottom). Precipitation combined with low evapotranspiration appeared to be important only in the "shoulder periods" (early December and early spring) when the ground was not frozen but the system was still overloaded and predicted evapotranspiration was low (Fig. 19). The difference between average and high effluent loading rates was important in determing how fast the system overloaded to the point of hydrologic surplus (Fig. 19, top). Loading rates had little influence, however, on how fast the hydrologic surplus was lost in the spring.

4.6.3 Summary of Modelling Exercise

A 34 year simulation showed that the climate of Southwestern Ontario (potential evapotranspiration and soil temperature) prevented evapotranspiration-based septic systems from functioning as designed. Systems could not maintain a hydrologic balance between October and April and so were predicted to exhibit hydraulic failure during this period. In a given year, systems would fail for 102 to 155 days, depending on the volume of effluent loaded to them. The modelling exercise supported observations of surface water impacts made during the monitoring portion of the study, and also suggested that monitoring in April and May missed the critical November to March period, when evapotranspiration was lowest because of frozen ground or snow cover and hence the probability of hydrologic failure was greatest.

5.0 CONCLUSIONS

1. A visual survey of 56 evapotranspiration-based systems and interviews with the owners found no obvious visible evidence of channelling, ponding or breakout of sewage, nor of odours and sponginess of the ground which would be consistent with failure of the systems. Four of the inspected systems did show evidence of failure, but all four had been built or were used improperly. Surveys were done in February and March when hydraulic loading was greatest but when any symptoms of failure could have been obscured by standing surface water or by snow cover.

2. Seeding of 30 systems with LiBr produced evidence of hydraulic loss to surface water from 14 properly built and maintained systems, or 47% of the total. Hydraulic connections between study systems and surface water lasted a maximum of 18 days at one site and a minimum of one day at eleven sites.

3. Tracer bacteria tests showed movement of bacteria into surface water at one site where no mantle had been installed and where the system may have been damaged by vehicle traffic.

4. Concentrations of nitrogen compounds (12 sites) and total phosphorus (2 sites) discharged from evapotranspiration-based systems were significantly elevated over those in adjacent receiving waters on the one day when samples were taken. Ammonia concentrations at 6 sites were significantly higher than the mean values measured in streams in the region and exceeded the PWQO at 4 of these sites. Although the degree of impairment appeared to be low compared to the quality of the immediate receiving waters, observations were not made at the time when impacts were most likely and sampling was neither extensive nor frequent enough to detect the full impacts of the systems.

5. Modelling of loadings to and losses from evapotranspiration-based systems over a 34 year period showed that, on average, evapotranspiration rates for Southwestern Ontario were only sufficient to assimilate effluent and precipitation loads between May and November. On average, evapotranspiration-based septic systems in Southwestern Ontario were predicted to have a hydraulic overload for 102 to 155 days per year.

6. Modelling of evapotranspiration-based systems showed that they could not maintain hydrologic balance from November to April. Their function was limited by low evapotranspiration rates in November and April, and by frozen ground and snow cover from December to March. The detection of any environmental impacts associated with their use is most likely in the November to March period, when hydraulic loading is greatest and evapotranspiration rates are limited by soil temperature.

7. Evaluation of the systems identified as malfunctioning in this study indicates that proper construction and operation is critical to performance of evapotranspiration-based systems.

5.1 SUMMARY

Whether based on climatic models of potential evapotranspiration or on direct monitoring of environmental impact; evapotranspiration-based septic systems are not an effective, year-round means of treating domestic sewage in Southwestern Ontario. Hydraulic connection of evapotranspiration-based systems wth adjacent surface waters was demonstrated in 47% of 30 systems studied. There was evidence of nutrient enrichment of adjacent surface waters by partially-treated sewage effluent at 66% of the study sites. There was no evidence that properly built and maintained evapotranspiration-based septic systems lost bacteria to receiving waters and no complaints from users or the community-at-large relating to their operation.

This study represents a partial compromise between the need for a full assessment and understanding of a poorly known technology, and the practical implementation of a study design. Interpretation of the study would have been improved by the inclusion of more piezometers - to monitor the volume and quality of effluent within these systems and to increase the probability of intercepting effluent, more intensive study of nutrient chemistry of piezometer samples and surface water adjacent to study sites and an extended monitoring period, to cover the November to March period when frozen ground prevents evapotranspiration.

Although routine operation of high densities of evapotranspiration-based systems could impair the quality of adjacent surface waters, the impacts of the approximately 1800 existing systems is likely negligible in comparison with the predominance of agricultural runoff, the overall poor quality of surface waters adjacent to the septic systems and their use in rural areas with low density residential development. The environmental impacts of evapotranspiration-based septic systems are of greatest potential concern where cumulative effects due to repetitive impacts at one site, repeated impacts over a large area or failures associated with extreme climatic events are considered. Not enough is known about the performance of conforming or alternative private septic systems, however, to make valid comparisons of the preferred means of on-site treatment of domestic sewage in heavy clay soils.

REFERENCES

Bennett, E. R. and K. D. Linstedt. 1978. Sewage Disposal by Evaporation-Transpiration. USEPA 600/2-78-163, NTIS Report No. PB 288 588, September 1978. 196 pp.

Bernhart, A. P. 1973. Treatment and Disposal of Waste Water From Homes by Soil Infiltration and Evapotranspiration. University of Toronto Press, Toronto, Canada. 173pp.

Bernhart, A. P. 1975. Return of Effluent to the Natural Cycle Through Evapotranspiration and subsoil-Infiltration of Domestic Wastewater. pp. 175-181 in : Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 1974. American Society of Agricultural Engineers, St. Joseph, Michigan.

Bernhart, A.P. 1985. Evapotranspiration, nutrient uptake soil infiltration of effluent water. A.P. Bernhart (Publ.) Toronto, Ont. 238p.

Fisheries and Environment Canada. 1978. Hydrological Atlas of Canada, Dept. Of Supply and Services Canada. EN37-26/1978. Ottawa, Ontario.

Gray, D.M. (ed.) 1970. Handbook on the Principles of Hydrology. National Research Council of Canada. 577pp.

Monteith, J.L. 1965. *Evaporation and Environment*. Symp. Soc. Exptl. Biol. 19: 205-234.

Morton, F.I. 1990. Studies in evaporation and their lessons for the environmental sciences. Cdn. Wat. Resources Journal 15: 261-286.

Oke, T.R. 1978. Boundary Layer Climates. Methuen, New York. 372 pp.

O'Neill, G.J. 1992. Clean Up Rural Beaches (CURB) plan for Big Creek and other watersheds in the Essex Region Conservation Authority. Final Report. March 30, 1992. Essex Region Conservation Authority.

Ontario Ministry of the Environment. 1982. Manual of policy, procedures and guidelines for on-site sewage systems.

Ontario Ministry of Environment and Energy. 1994. Water Management Policies, Guidelines. Provincial Water Quality Objectives of the Ministry of Environment and Energy. PIBS 3303E. July 1994. P. 10.

Ontario Ministry of Environment and Energy. 1995. Technical guideline for individual on-site sewage systems. Water quality impact risk assessment.

Pereira, A.R., N.A. Villa Nova, A.S. Pereira, V. Barbieri. 1995. A model for the class A pan coefficient. Agricultural and Forest Meteorology 76: 75-82.

Perkins, R.J. 1980. Onsite Wastewater Disposal. Lewis Publishers, Chelsea, Michigan. 251 pp.

Robertson, W.D. 1995. Development of steady-state phosphate concentrations in septic system plumes. J. Contaminant Hydrology 19: 289-305.

Sokal, R.R. and F.J. Rohlf. 1973. Introduction to biostatistics. W.H. Freeman and Co. San Fancisco. 368 pp.

United States Environmental Protection Agency (USEPA). 1980. Design Manual: Onsite Wastewater Treatement and Disposal Systems. EPA 625/1-80-012. October 1980. 391pp.

Viessman, W. Jr., T.E. Harbaugh and J.W. Icnapp. 1972. Introduction to Hydrology. Intext Educational Publishers. New York. 415 p.

Walker, W.J. and B. Branham. 1992. Environmental Impacts of Turfgrass Fertilization. Ch. 3 *in* Balogh, J.C. and W.J. Walker. (eds). Golf Course Management and Construction, Environmental Issues. Lewis Publ. , Chelsea, MI. 951 pp. ISBN 0-87371-742-2.

Wood, J.S.A. 1993. Migration of septic-system contaminated groundwater to a lake in a Precambrian Shield setting: a case study. M.Sc. thesis. Univ. Of Waterloo. 371 pp.

APPENDIX I : SURVEY FORM USED FOR INSPECTION OF EVAPOTRANSPIRATION-BASED SEPTIC SYSTEMS IN ESSEX COUNTY

Ministry of
Suitable site for Piezometre Installation: __________
Date: __________________
Environment
and Energy

Evapotranspiration (Partially-Raised) Septic Bed Survey

Name of Owner	Township / Municipality	
Address	Concession	Lot No
	Certificate of Approval Issued	Use Permit Issued
Telephone No.	Move-In Date	
Alternate Tel. No.	Original Owner (Yes/No)	If No, Purchase Year

System Details

Any Additions or Renovations to Dwelling

Number of People in Dwelling	Adults	Adolescents	Children

State Number of	Flush Toilets	Showers/Bathtubs	Basins/Sinks	Jacuzzi	Washing Machine	Dishwasher	Sewage Ejector
Water Saving	Low Volume	Low Flow	Aerators				

System Management Information

Number of Pumpouts Since Installation	Years Pumpouts Occurred	Septic System Additives

Septic System History (any perceived problems)

Has system been exposed to any abnormal use in the past 3 days?

Water usage Habits (i.e. staggering laundry loads)

Sump Pump (i.e. inputs and outlet)

Exterior System Inspection

Inground Sprinkler System (Yes/No)	Utility Corridor Near System (Yes/No)	Interfering Vegetation	Driveways Near Bed

Final grading and seeding prior to use?

Meteorological Conditions Previous 3 Days	Meteorological Conditions Present

Visual Inspection

Unusual Vegetation Growth	Odour (Yes/No)
Signs of Overflow	Overflow Installed (Yes/No)

Spongy Bed Area / Frozen

Evidence of Ponding, Breakout

Standing Water in Adjacent Swales or Municipal Drains

Description of Surface Water Management (i.e. berms, contouring of crown, rainwater leaders)

Condition of Abutting Lands (i.e. saturated, standing water, flat)

Subsurface Conditions

Level (Inches) Type

Lot Diagram and Sewage System Plan